Consistent Radiometric Calibration of The Landsat MSS Archive

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- Acknowledgements:

  This work was supported by the NASA Landsat Project Science office and USGS EROS

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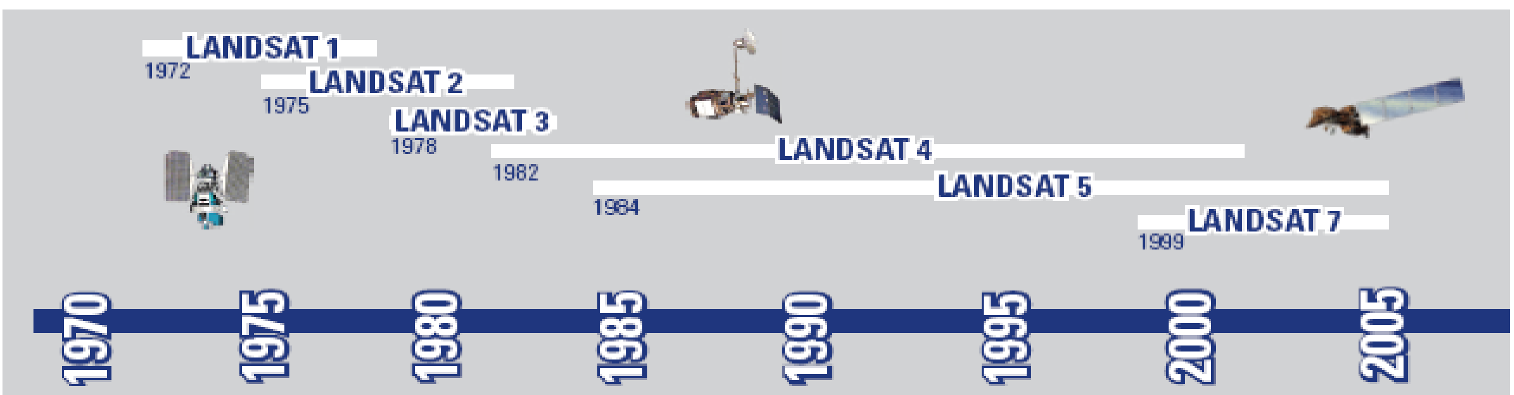
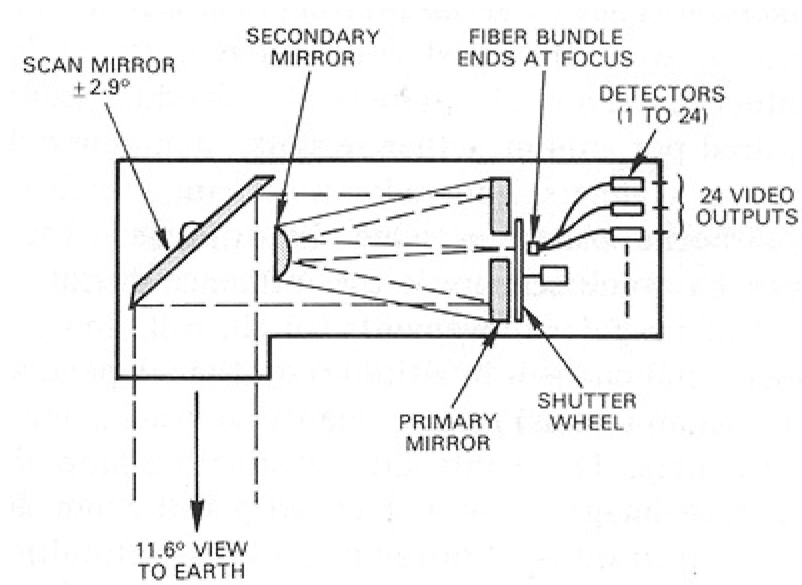
Landsat-1 to -7 Characteristics

Satellite	Launched	Decommissioned	Sensors	Orbit
Landsat-1	July 23, 1972	January 6, 1978	RBV*, MSS	18 days/900 km
Landsat-2	January 22, 1975	February 25, 1982	RBV, MSS	18 days/900 km
Landsat-3	March 5, 1978	March 31, 1983	RBV, MSS	18 days/900 km
Landsat-4	July 16, 1982	June 15, 2001	MSS, TM	16 days/705 km
Landsat-5	March 1, 1984	**Still Alive after more than 25 years**	MSS, TM	16 days/705 km
Landsat-6	October 5, 1993	Failure upon launch	ETM	16 days/705 km
Landsat-7	April 15, 1999		ETM+	16 days/705 km



*The RBV (Return Beam Vidicon) cameras did not achieve the popularity of the MSS sensor

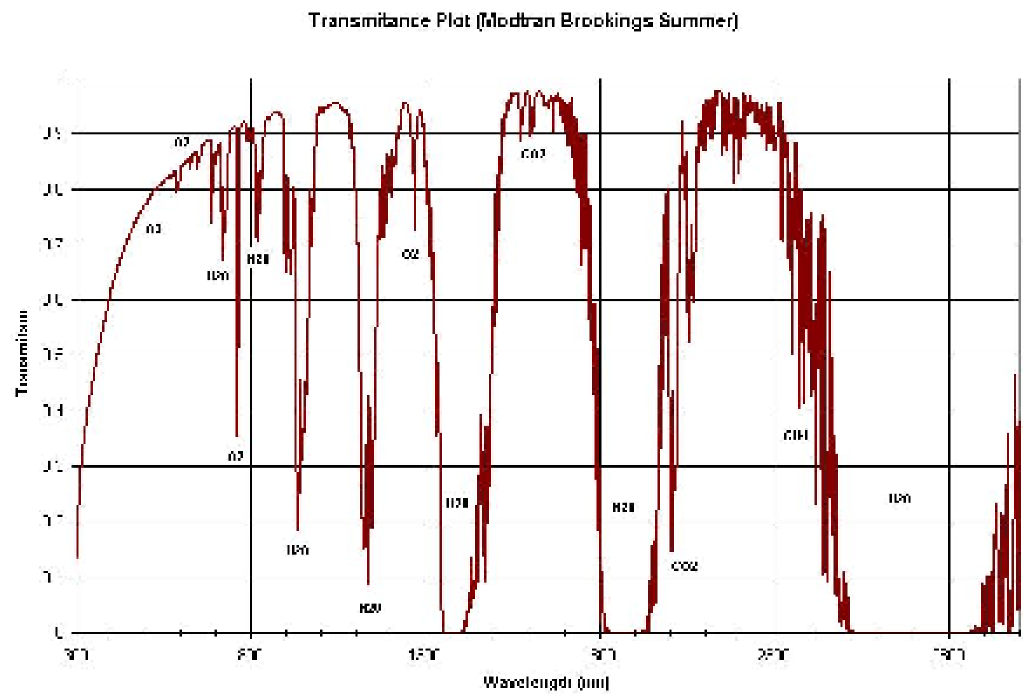
MSS Properties



- Multispectral Scanner
- Nominal 80m GSI
- 4 Spectral Bands
- Detectors
  - Photomultiplier Tubes—bands1-3
  - Silicon Photodiodes—band 4
- Radiometric calibration based on internal lamp system
- All data in the USGS EROS archive have been radiometrically corrected.

Spectral bands of MSS

Band No.	Spectral Range (µm)
1	0.5 - 0.6
2	0.6 – 0.7
3	0.7 – 0.8
4	0.8 – 1.1



- MSS band 3 has water and oxygen absorption bands at 725 nm and 760 nm respectively.
- MSS band 4 includes an H_2O absorption band at 940 nm.

Radiometric formulation

- MSS data in the USGS archive is already radiometrically processed based on internal calibration system.
- The calibrated pixels (Q_{CAL}) can be converted to at-sensor radiance (L_λ) and top-of-atmosphere (TOA) reflectance (ρ) using the following equations:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{CALMAX}} \right) Q_{CAL} + LMIN_\lambda \qquad \rho = \left(\frac{\pi L_\lambda d^2}{ESUN_\lambda \ \mathrm{Cos}\theta} \right)$$

where,

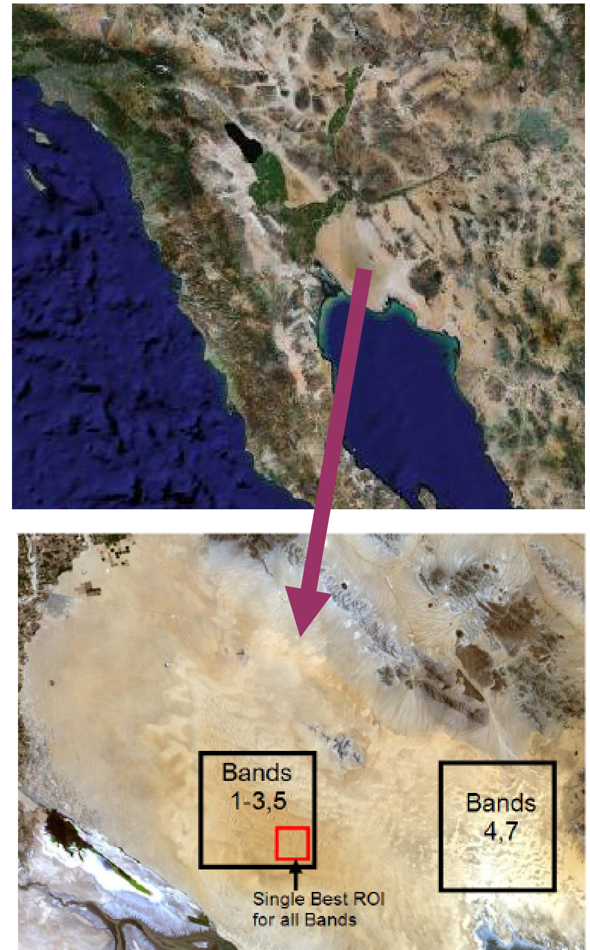
- $LMIN_\lambda$ and $LMAX_\lambda$ are known as post-calibration dynamic ranges and their values are given for all five MSS sensors
- d = Earth-sun distance in astronomical units (AU),
- $ESUN_\lambda$= mean solar exoatmospheric spectral irradiances, and
- θ = solar zenith angle for the image portion of interest

Pseudo-Invariant Calibration Site (PICS)

- Pseudo-invariant calibration sites are temporally and spatially stable natural ground targets that are ideally bright, spatially homogeneous, spectrally flat, and are generally located in arid regions.
- Pseudo-invariant calibration sites can be used to
  - Monitor long term radiometric gain of satellite sensors (e.g. Landsat-5 TM)
  - Cross-calibrate multiple satellite sensors that are unable to take image data from the same ground target under simultaneous conditions
- However, the use of this technique requires adequate data collection from invariant sites on a repetitive basis.
- Key pseudo-invariant sites frequently used for Landsat cal-val are: *Libya-4 desert (P181R40) and Sonoran desert (P38R38).*

Sonoran Desert: An invariant site in North America

- Large African pseudo-invariant desert sites are considered to be the optimal sites in the world for sensor calibration.
- Many satellite sensors have a limited archive of data from these sites.
- Sonoran desert (on the Mexican American border) was found to have invariant regions comparable to the Saharan desert.
- The lifetime response of L5 TM to these regions agree with LUT07 calibration model to within **1-2% in the visible and 2-3% in the SWIR.**



The most invariant regions in Sonoran Desert

Reference: Daniel L. Morstad, Dennis L. Helder, "*Use of pseudo-invariant sites for long-term sensor calibration*", IGARSS 2008

Lifetime Radiometric Calibration Stability and Consistency of Landsat-1 through -5 MSS Sensors

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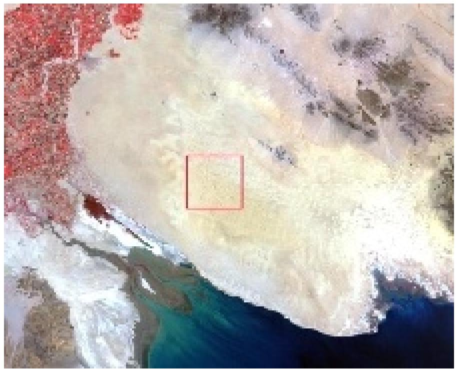
Methodology

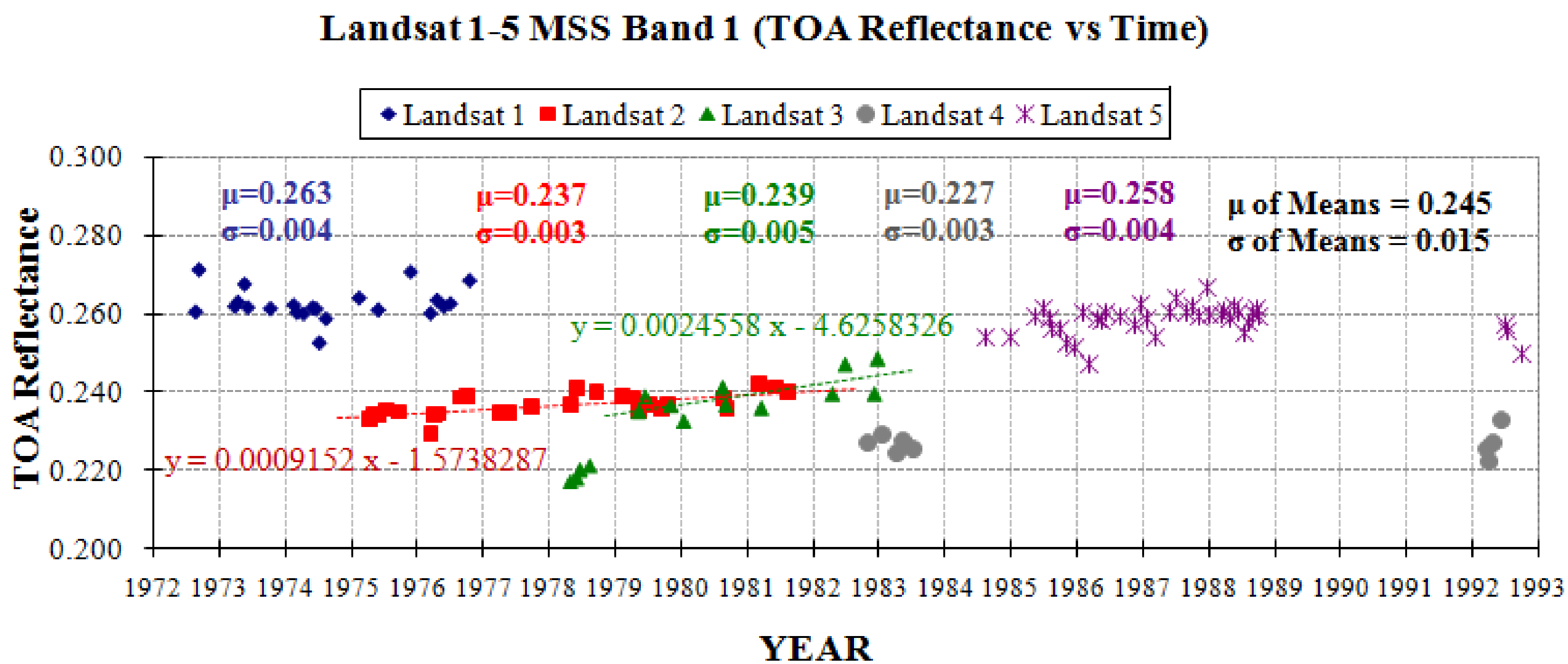
- Good quality and cloud free scenes from Sonoran Desert were searched for all 5 MSS sensors.
- Varieties of scenes used: MSS-X, MSS-P, and MSS-A
- TOA reflectance values were derived for the specified 250*250 pixel (MSS-X/A) ROI for all scenes.
- A lifetime instrument response was derived by plotting TOA reflectance against time for each sensor.



250*250 pixels ROI

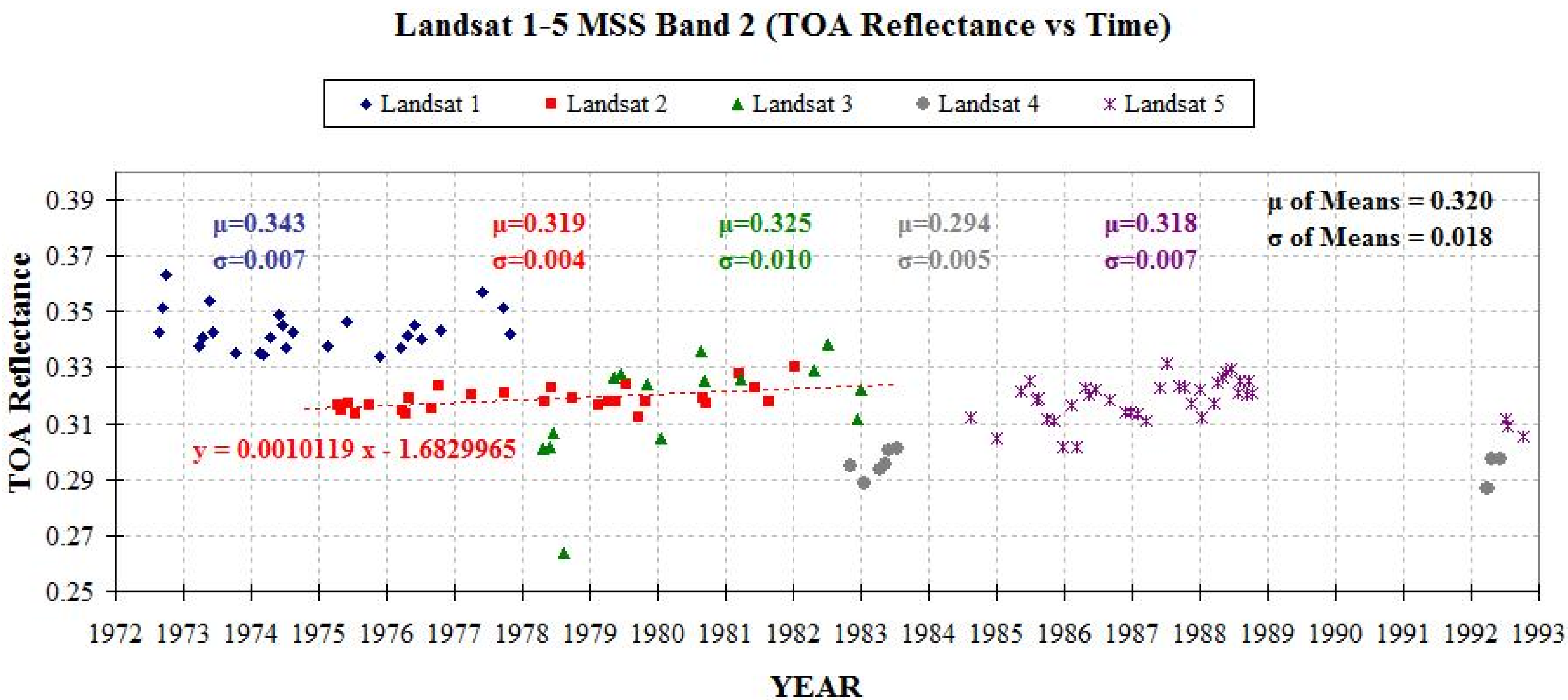
- Atmospheric and BRDF effects are not accounted for initially.

Results: Band 1



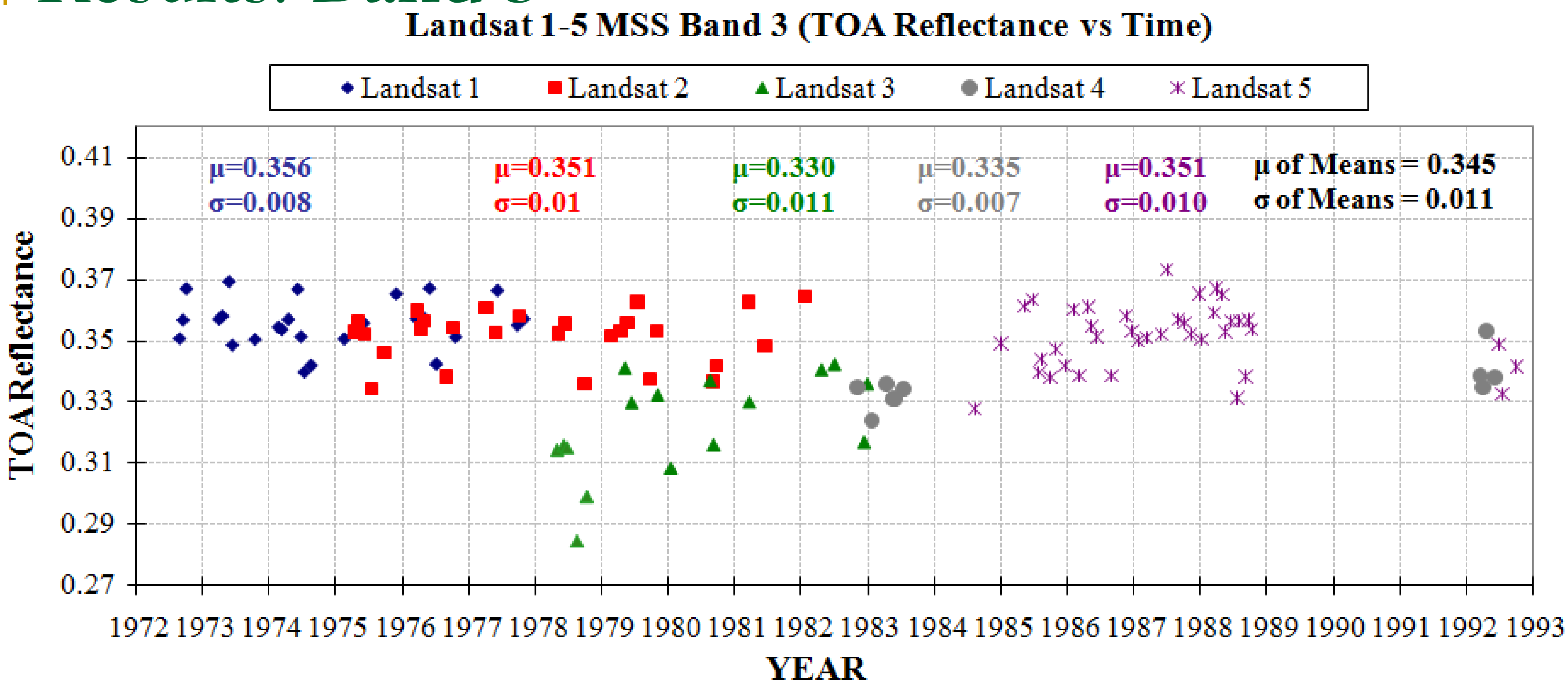
- Radiometric calibration of MSS sensors show good stability over lifetime.
- Pre-1979 data from Landsat-3 are not consistent with the post 1979 data.
- Landsat-1 and -4 exhibit the maximum inconsistency (16%) in calculating the TOA reflectance.
- Landsat-2 and -3 have increasing response trend supported by statistical tests.

Results: Band 2



- Landsat-2, -3, and -5 mean TOA reflectance agree within 1%.
- Landsat-1 and -4 again exhibit the maximum inconsistency (17%) in calculating the TOA reflectance.
- Slightly increasing response trend of Landsat-2 is supported by statistical tests.

Results: Band 3



- Landsat-1, -2, and -5 calibration seems consistent within 1%.
- Landsat-3 and -4 agree in the calculation of TOA reflectance within 2%.
- No trend in any response was supported by statistical tests.

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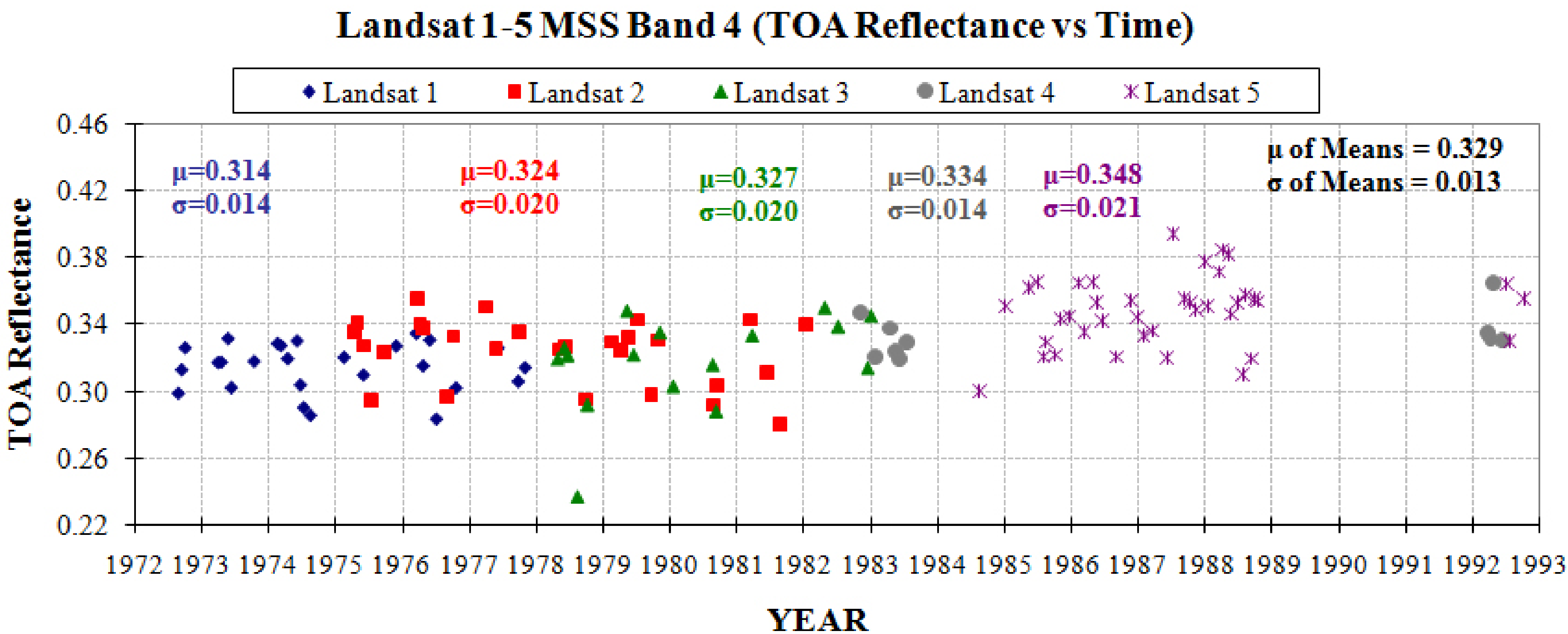
Results: Band 4



- Landsat-1 through -4 calibration seems consistent within 6%.
- Variability of data within each sensor is comparatively higher because band 4 is susceptible to the water vapor content in the atmosphere.
- No clear trend exists in any sensor.

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Summary of Lifetime Stability/Consistency of MSS sensors

- Data from each MSS sensor indicates better than expected radiometric stability.
- Absolute gains of all 5 MSS sensors exhibit a maximum difference of 17%.

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Cross-calibration of L1 MSS to L2 MSS

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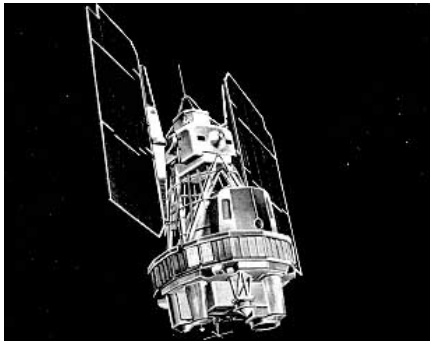
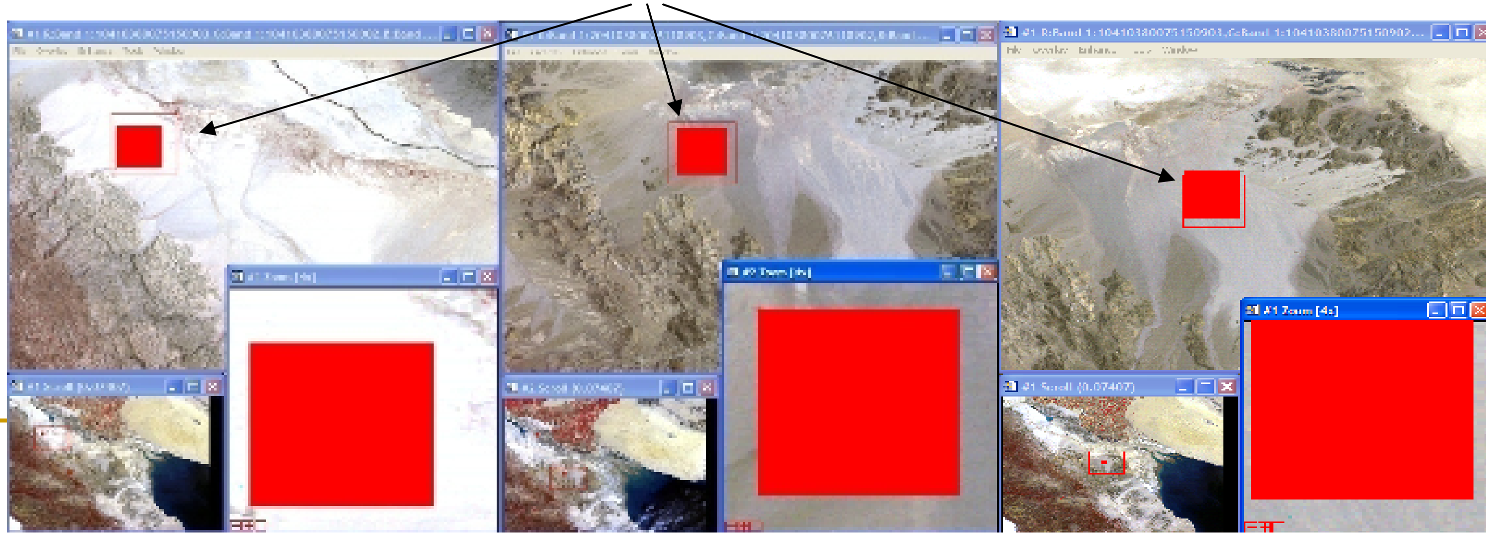


Background

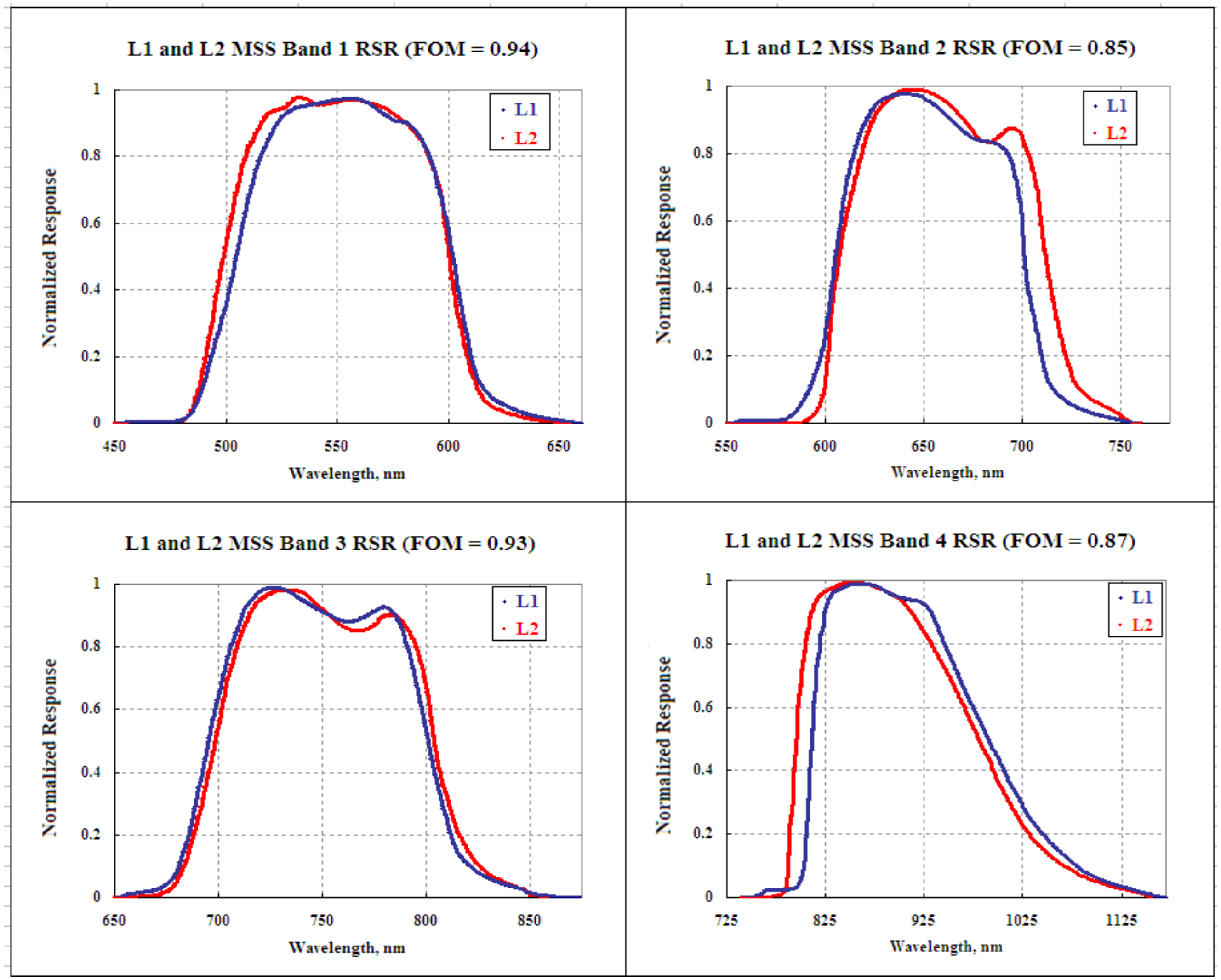
- Six pairs of near-coincident scenes from Sonoran desert are selected.
- For better regression, some additional ROIs with different reflectance values were selected.

Scene Pairs used (6), Total 9 ROIs	
LM10410381975150AAA04	LM20410381975159AAA05
LM10410381976073AAA02	LM20410381976082AAA01
LM10410381976109AAA02	LM20410381976100AAA01
LM10410381976109AAA02	LM20410381976118AAA04
LM10410381976289AAA04	LM20410381976280AAA03
LM10410381977262AAA04	LM20410381977274AAA01

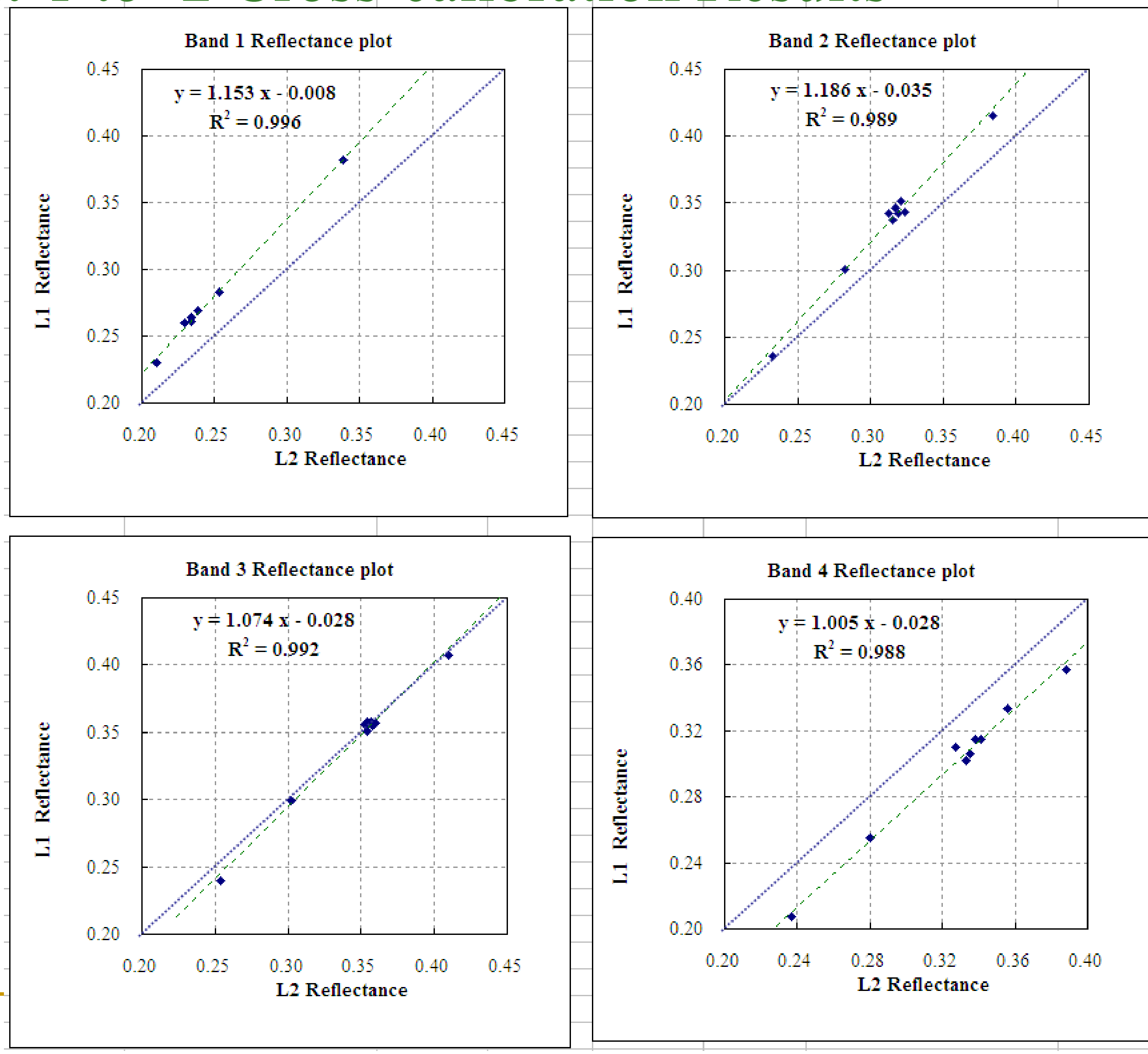
Additional ROIs

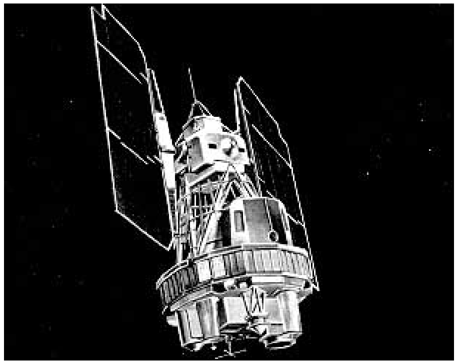


RSR Profiles of Landsat-1 and -2

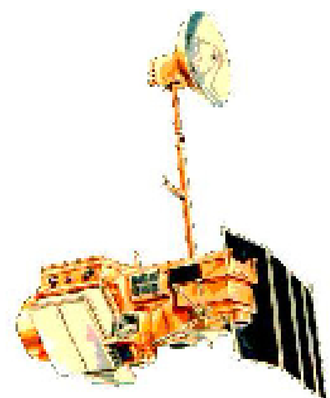


Landsat-1 to -2 Cross-calibration Results





Cross-calibration of L2 MSS to L4 MSS



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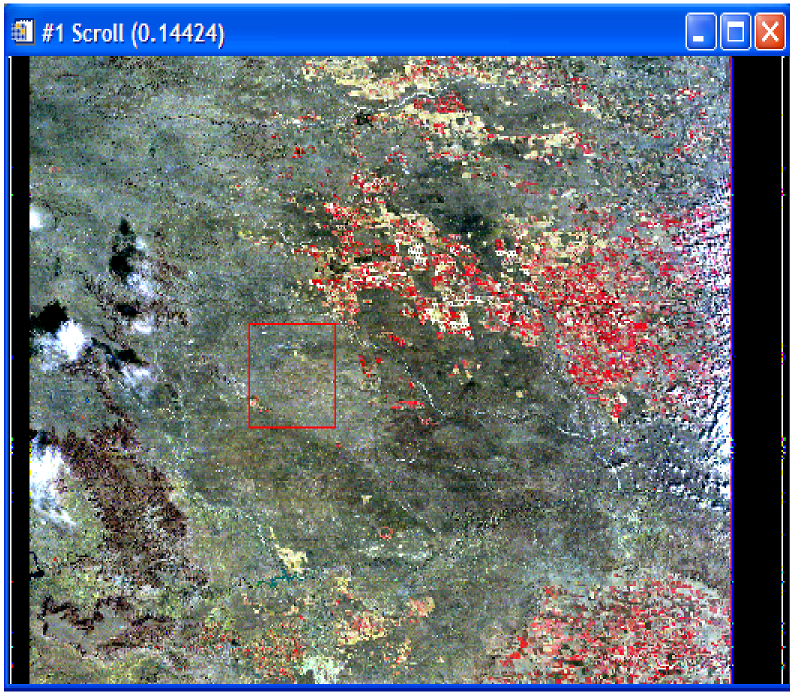
Background

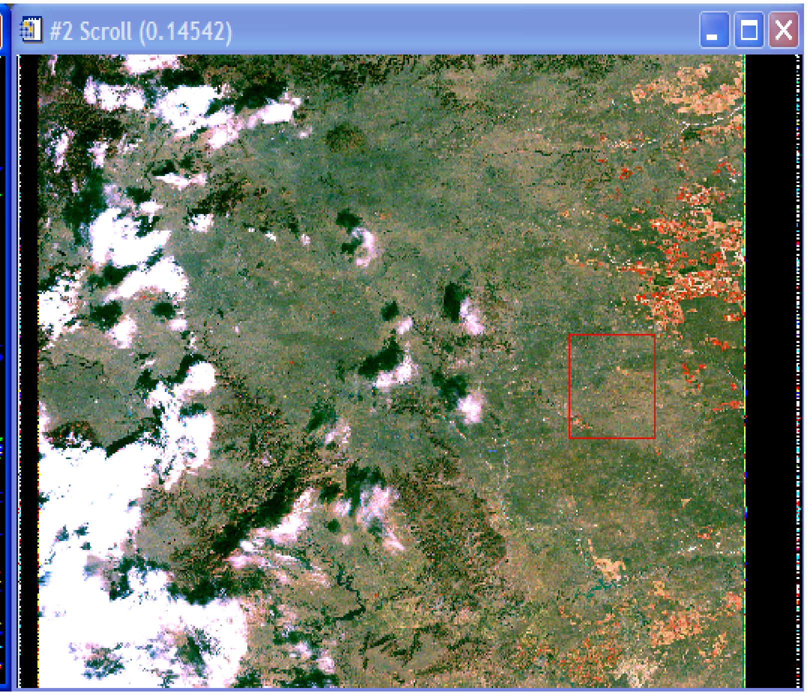
- The different temporal resolution of Landsat-2 and -4 (18 days vs. 16 days) provided an opportunity to these instruments on November 9, 1982 to acquire *almost simultaneous image data within minutes*.
- Three pairs of scenes selected for this work.

Pair No.	Scene Identifier	Date and Time Acquired (YYYY:DOY :HH:MM:SS)	WRS Path	WRS Row	WRS Type	Acquisition Quality	Sun Azimuth (°)	Cloud Cover
1	LM20340371982313AAA03	1982:313:16:56:05	34	37	1	9	149	10
	LM40320371982313AAA03	1982:313:17:00:04	32	37	2	9	150	30
2	LM20340341982313AAA03	1982:313:16:56:00	34	34	1	9	151	10
	LM40320341982313AAA03	1982:313:16:59:05	32	34	2	9	152	40
3	LM20340351982313AAA03	1982:313:16:55:04	34	35	1	9	151	10
	LM40320351982313AAA03	1982:313:16:59:02	32	35	2	9	151	20

The difference in sun azimuth arises due to a drift in the scene center.

An Example Scene Pair





LM20340351982313AAA03
1982:313:16:56:00
Sun Elevation = 31°
Sun Azimuth = 151°

LM40320351982313AAA03
1982:313:16:59:05
Sun Elevation = 32°
Sun Azimuth = 151°

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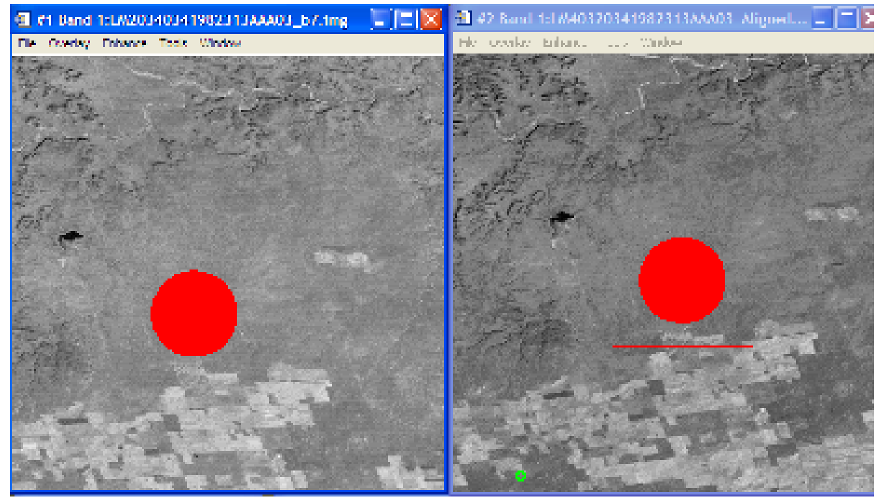
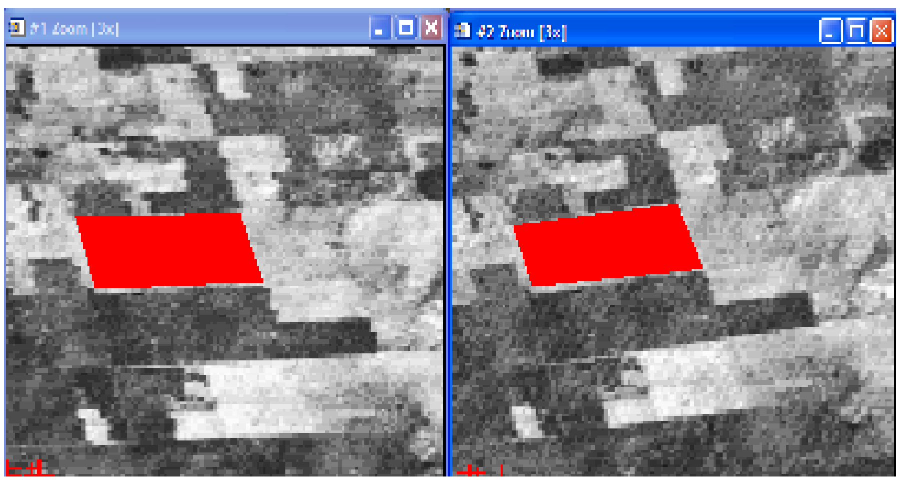
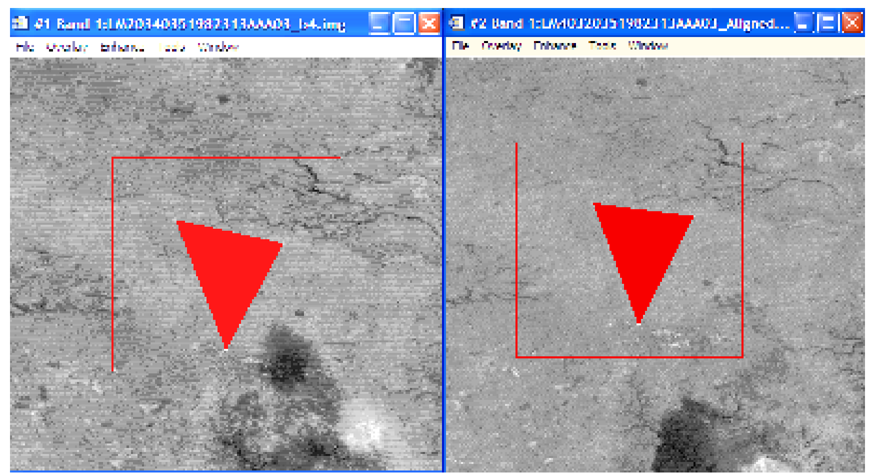
Region of Interest

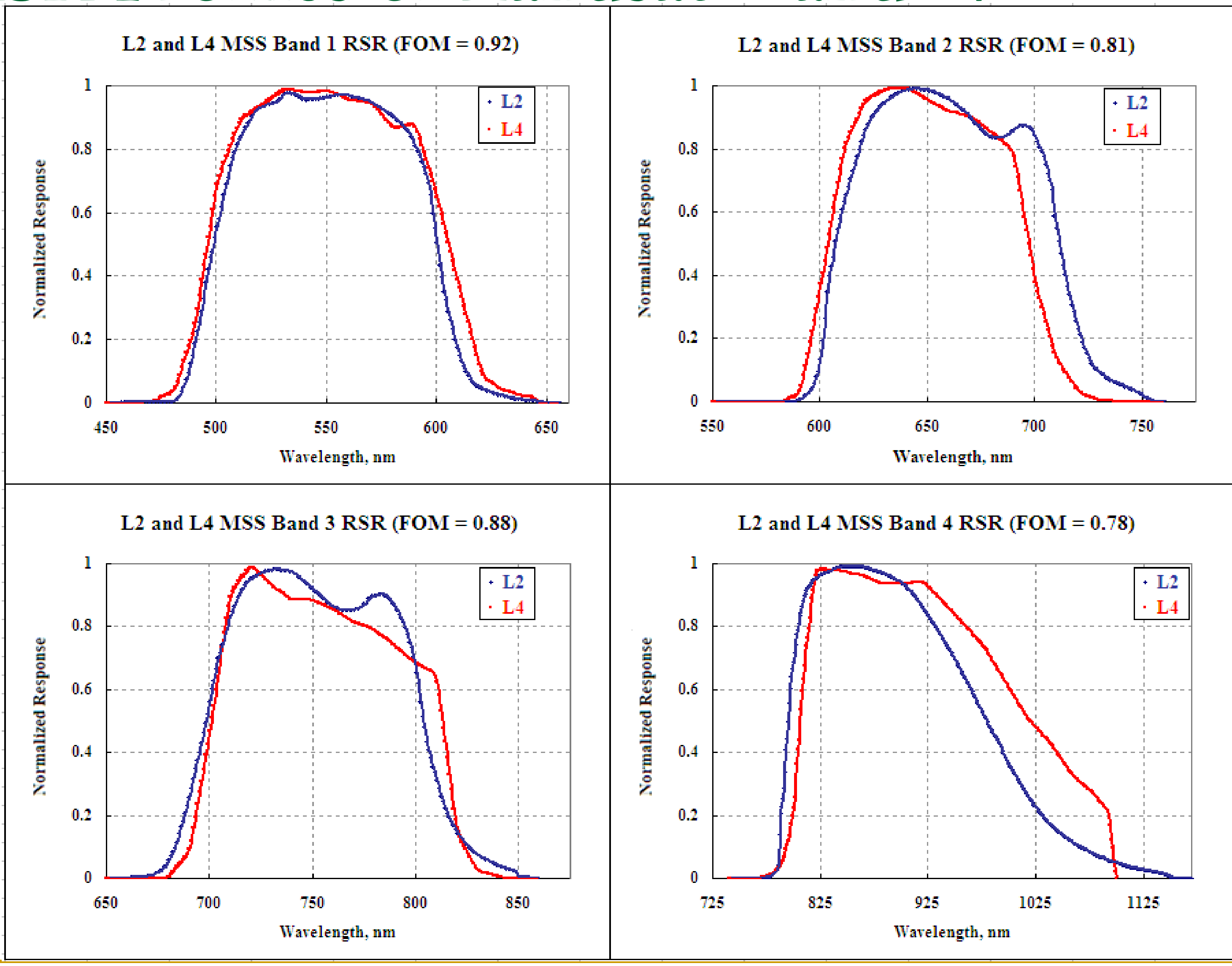
- Since none of these acquisitions are from known invariant sites, defining precisely geolocated ROI is a real challenge.
- Geographical features were used to avoid any misregistration error.



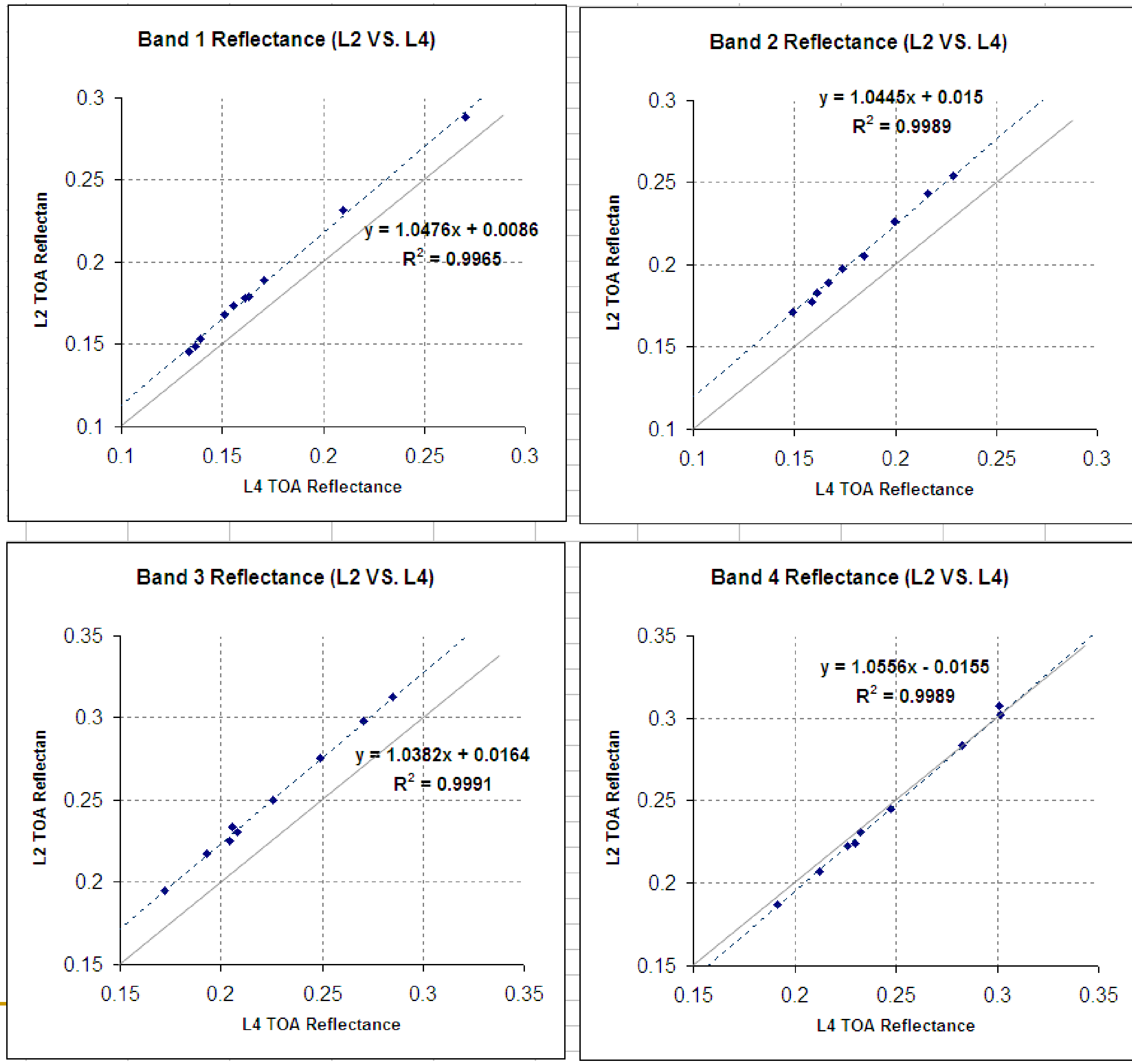




RSR Profiles of Landsat-2 and -4



Landsat-2 to -4 Cross-calibration Results



Cross-calibration of L3 MSS to L4 MSS

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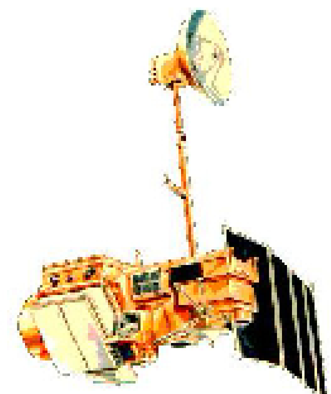
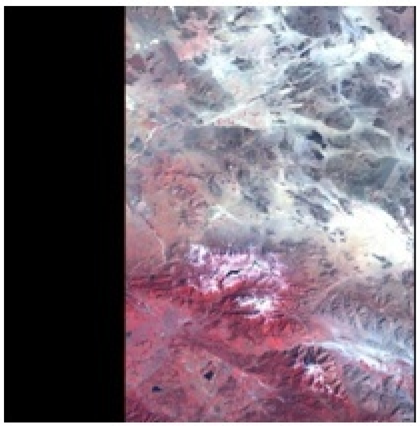
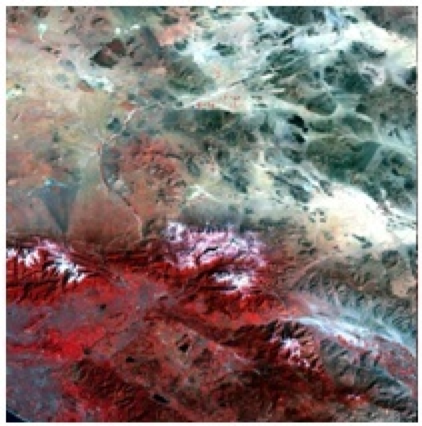


Background

- The different temporal resolution of Landsat-3 and -4 (18 days vs. 16 days) also provided an opportunity to these instruments to follow ***identical paths on January 20, 1983 within minutes.***
- Two pairs of good scenes are selected from this dataset to cross-compare the responses of Landsat-3 and -4.



LM30430361983020AAA03
1983:020:17:47:04



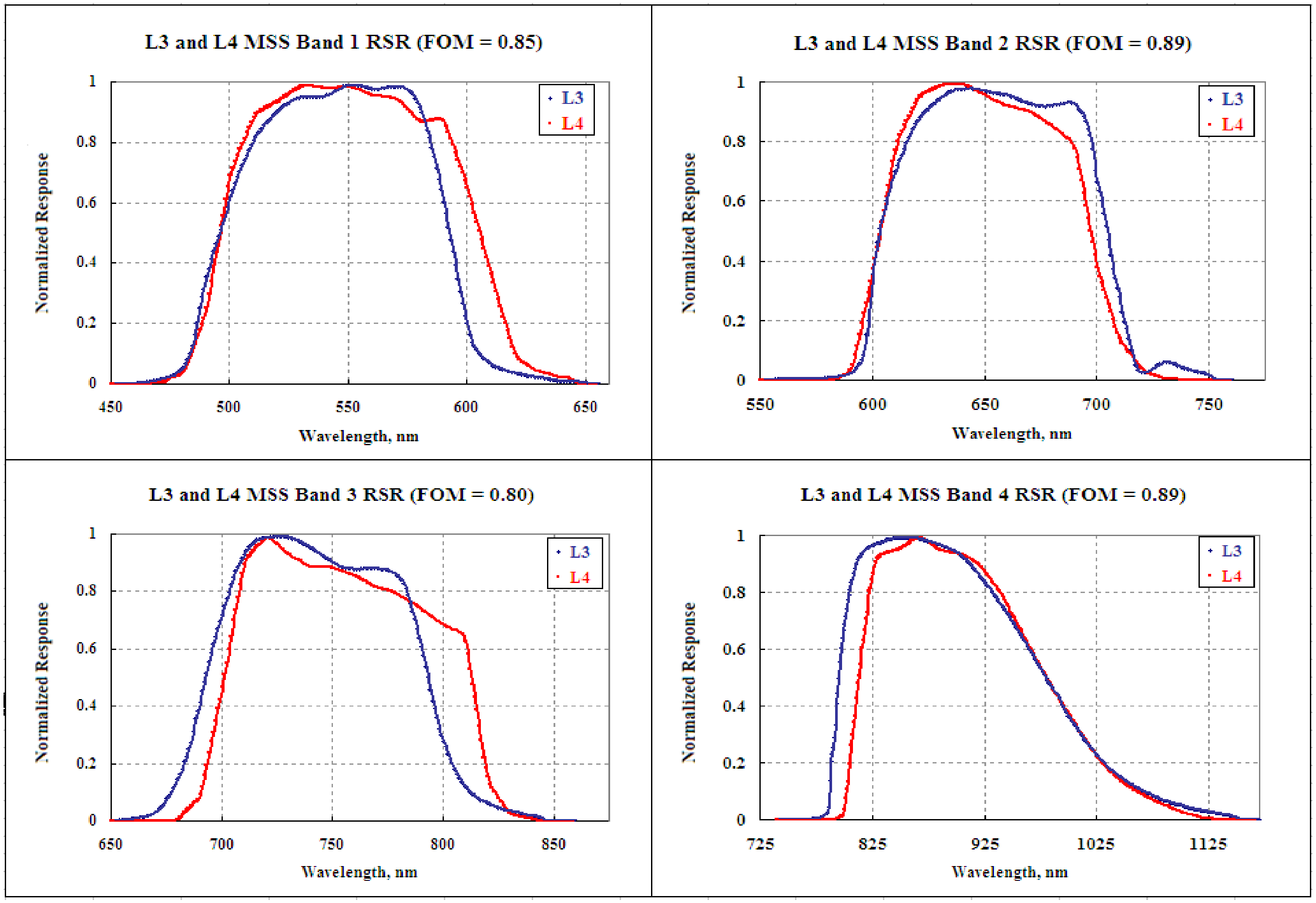
LM40400361983020AAA03
1983:020:17:51:00

LM30170401983012AAA03
1983:012:15:20:00

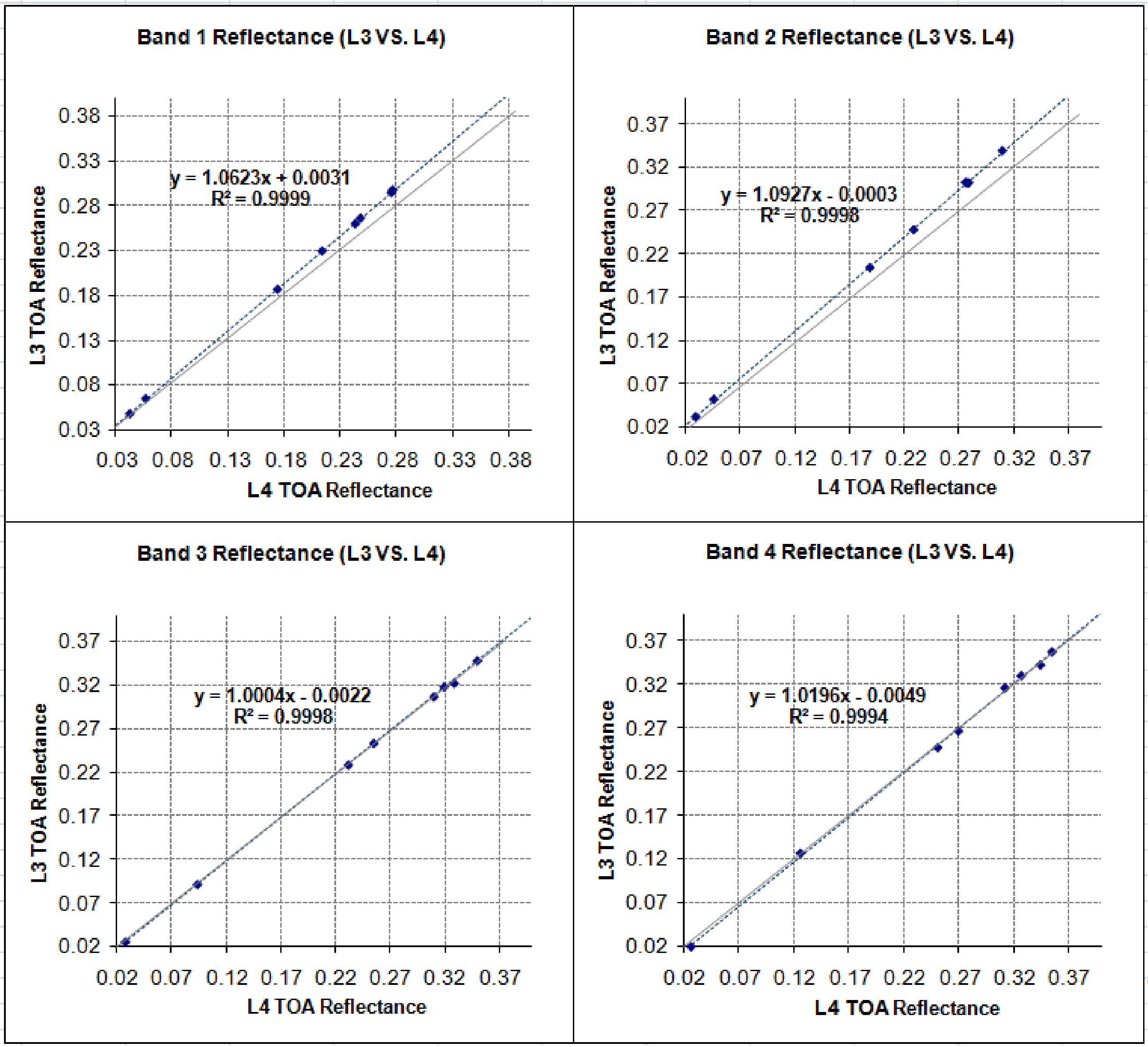
LM40160401983012AAA03
1983:012:15:24:00

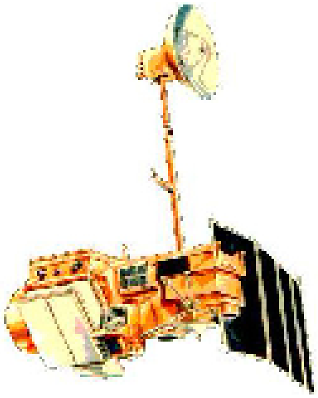
Altogether eight ROIs were defined in the homogeneous areas on the scenes.

RSR Profiles of Landsat-3 and -4



Landsat-3 to -4 Cross-calibration Results





Cross-calibration of L4 MSS to L5 MSS

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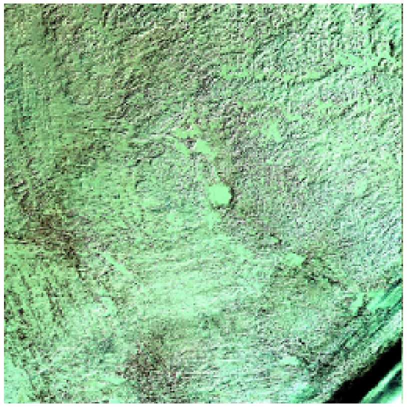
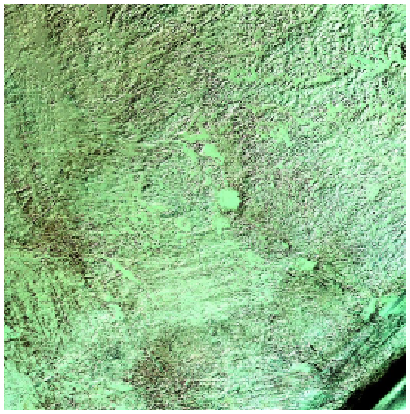
Background

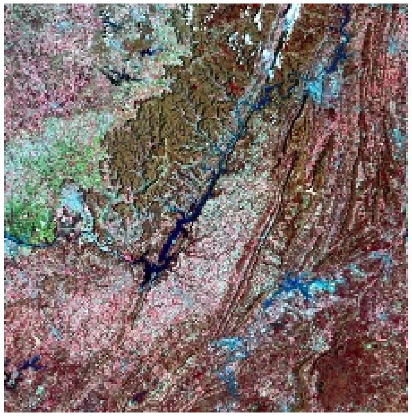
- Immediately after launch, the Landsat-5 was initially placed in a tandem orbit close to that of Landsat-4.
- The data acquired during this period was almost simultaneous with a difference of few seconds.
- Two pairs of good scenes were selected from this dataset to cross-compare the responses of Landsat-4 and -5.



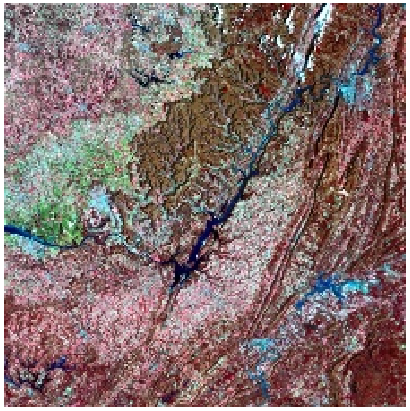
LM40200181984075XXX03
1984:075:15:38:04



LM50200181984075AAA03
1984:075:15:38:02



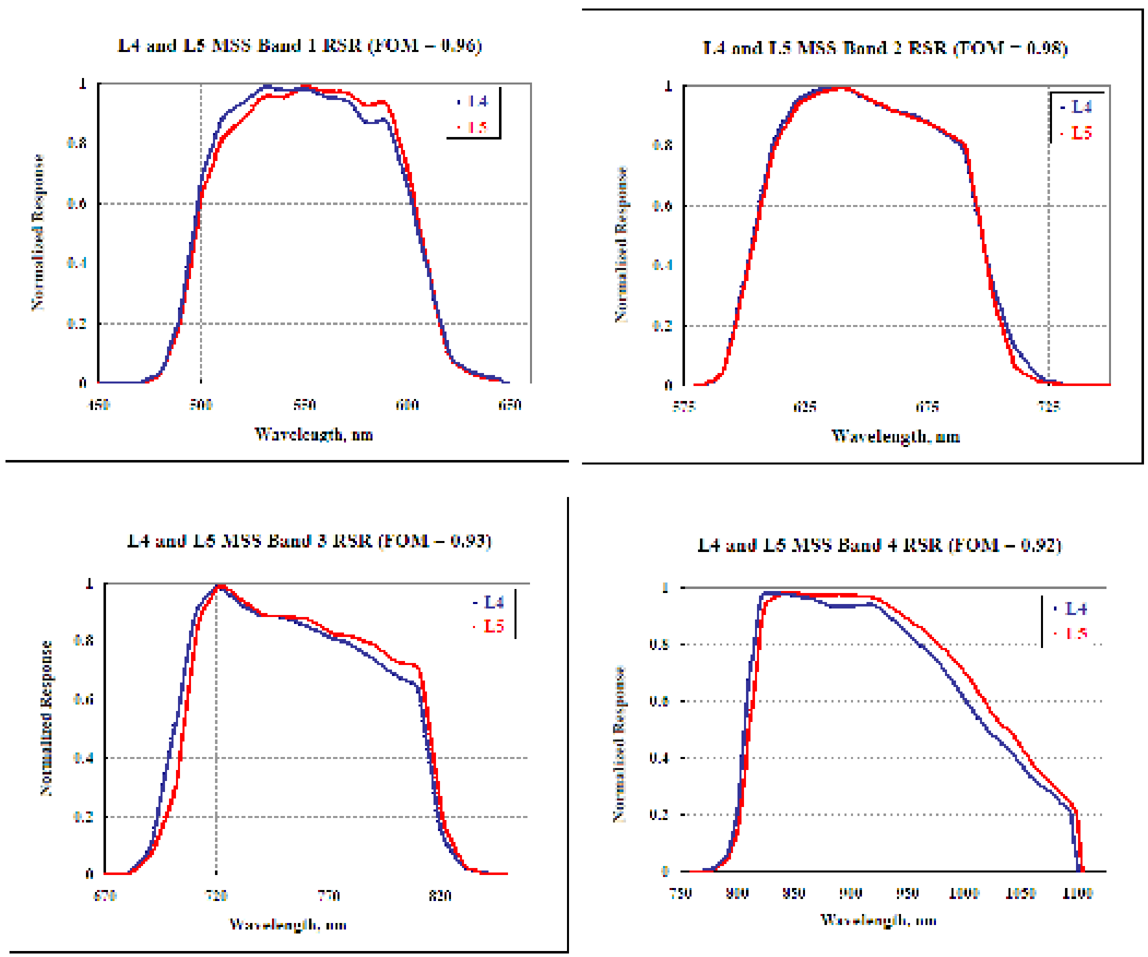
LM40200361984075AAA04
1984:075:15:45:05



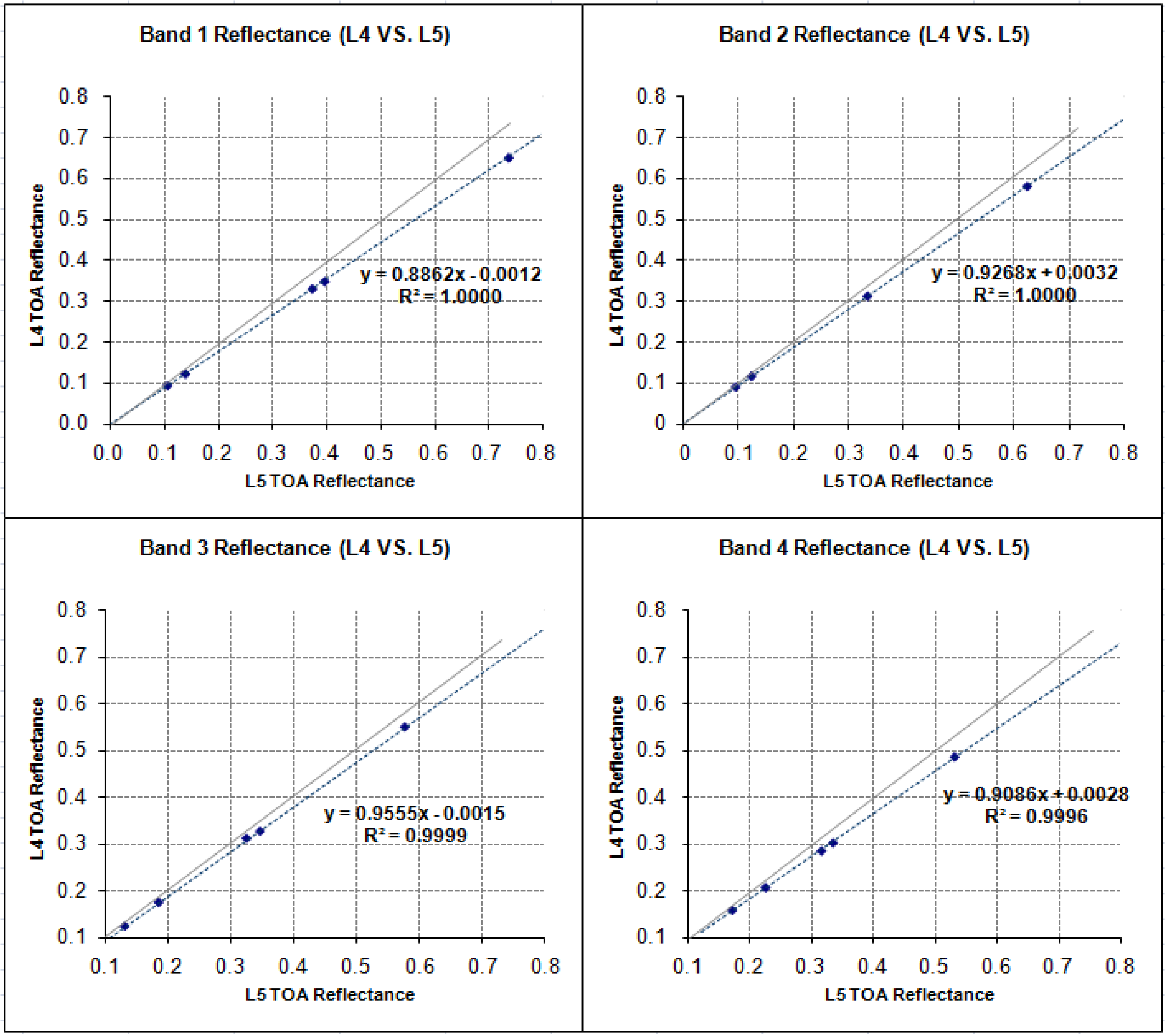
LM50200361984075AAA03
1984:075:15:45:03

Initially five precisely geolocated ROIs were defined on the scenes.

RSR Profiles of Landsat-4 and -5



Landsat-4 to -5 Cross-calibration Results



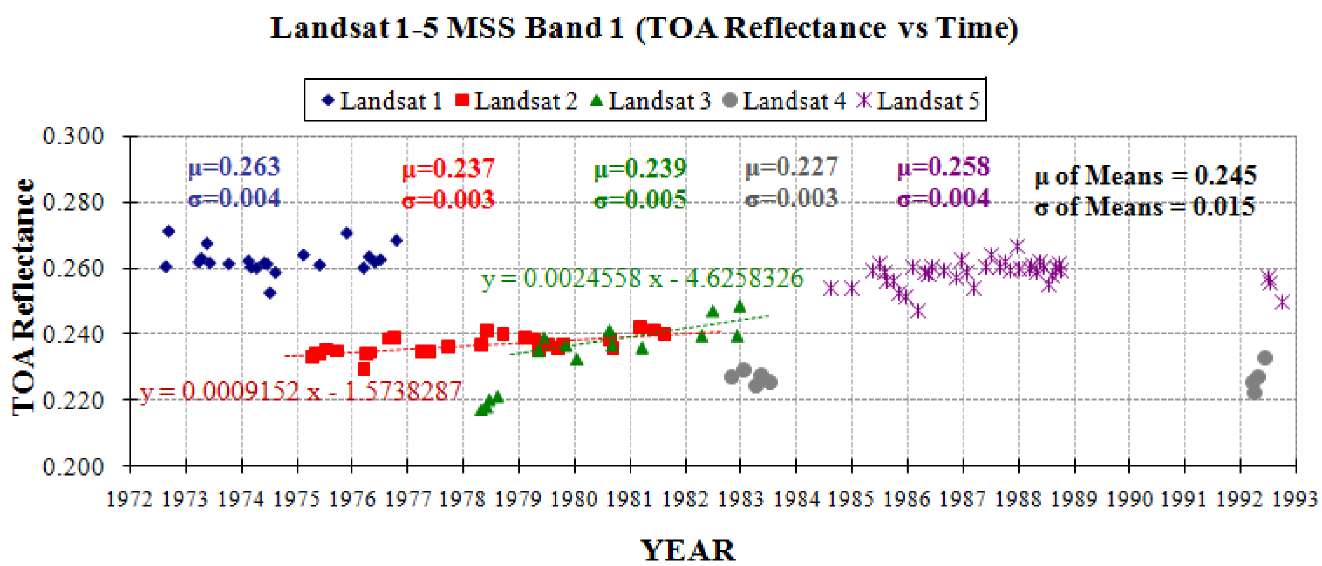
Validation of Cross-calibration Results

Methodology

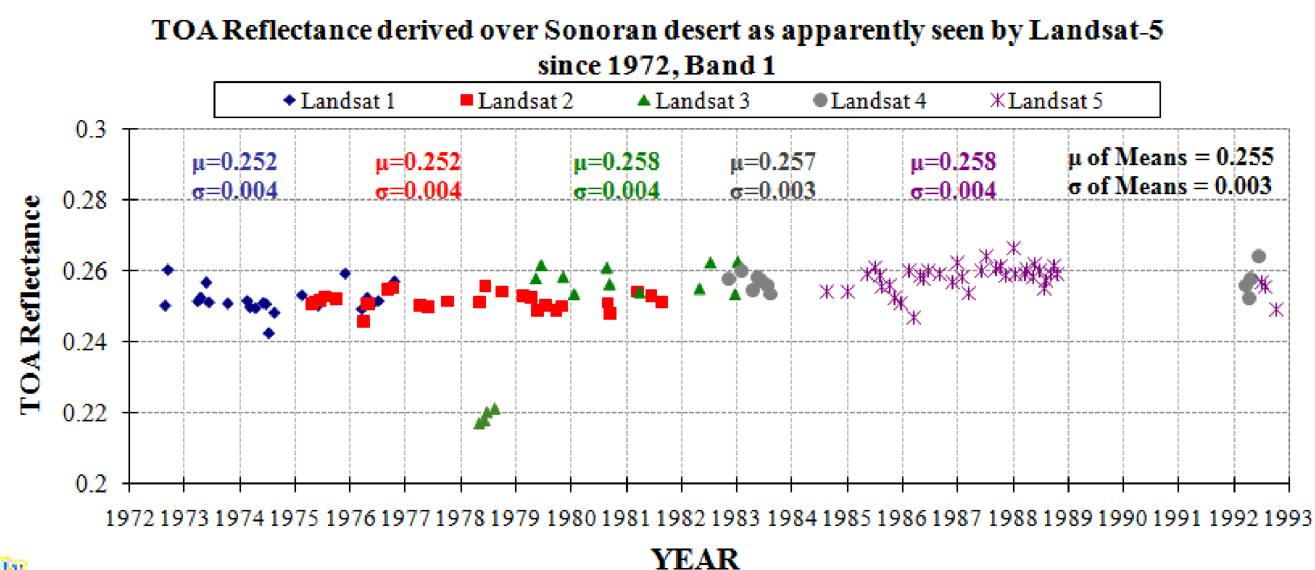
- Sonoran desert site is selected again for validation of cross-cal results.
- Following assumptions are made:
  - The Sonoran desert site is stable from 1972 to 1992.
  - Any genuine trend observed in the instrument response to this site is the characteristics of the instrument itself.
- Landsat-1 through -4 MSS data from Sonoran desert were transformed to apparent Landsat-5 data using the cross-calibration connections established in the previous part of this presentation.
- Time factor was introduced in the cross-calibration results of Landsat-2 band 1 and 2, and Landsat-3 band 1 to account for the trends they showed in their lifetime responses to Sonora.
- Pre-1979 data from Landsat-3 are left unaltered.

Results: Band 1

Before Cross-calibration applied



After Cross-calibration applied



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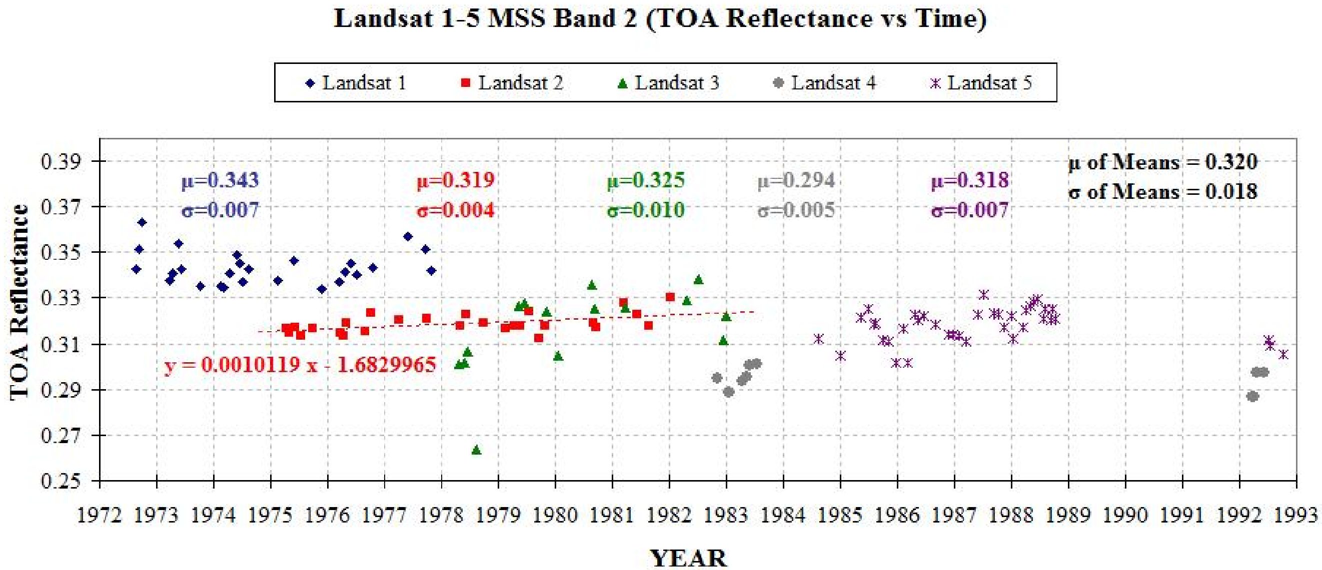
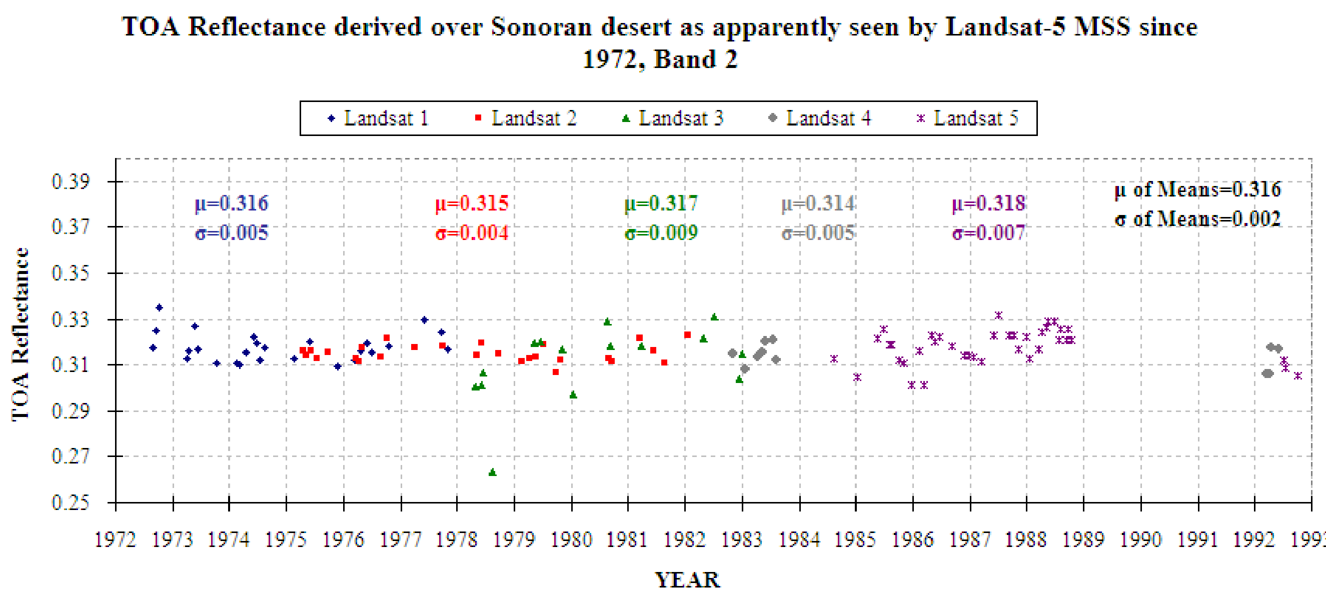
Results: Band 2

Before Cross-calibration applied



After Cross-calibration applied



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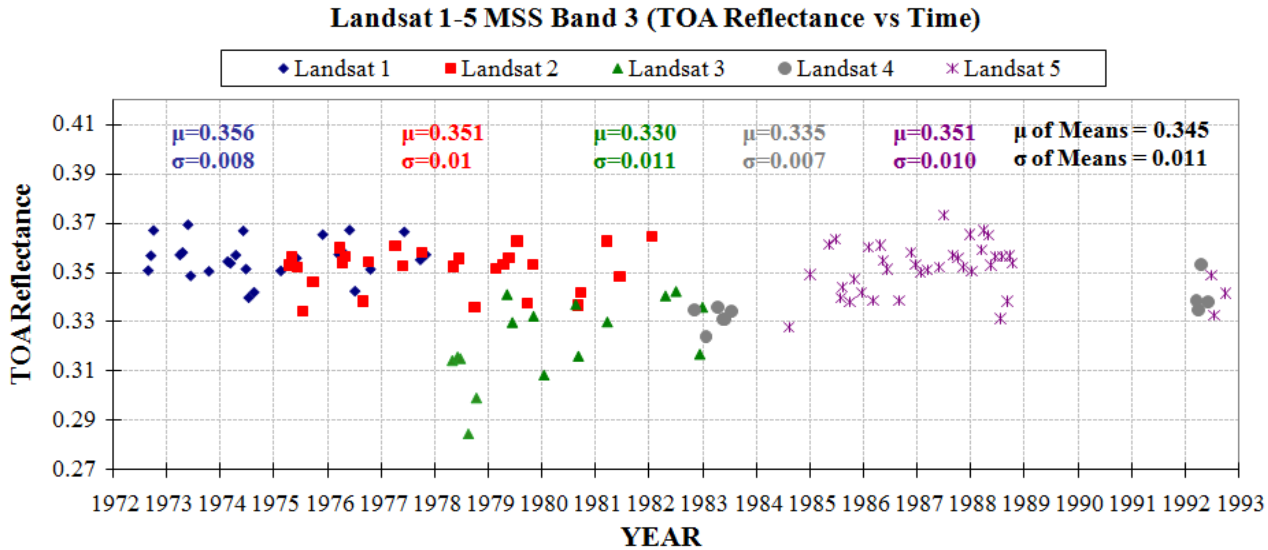
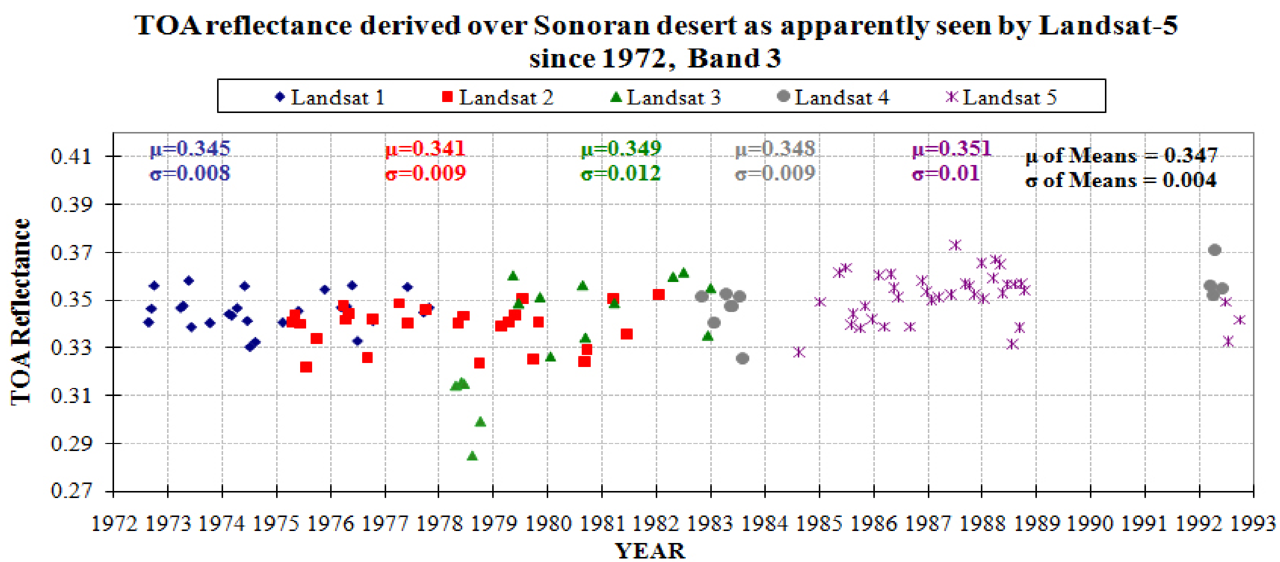
Results: Band 3

Before Cross-calibration applied



After Cross-calibration applied



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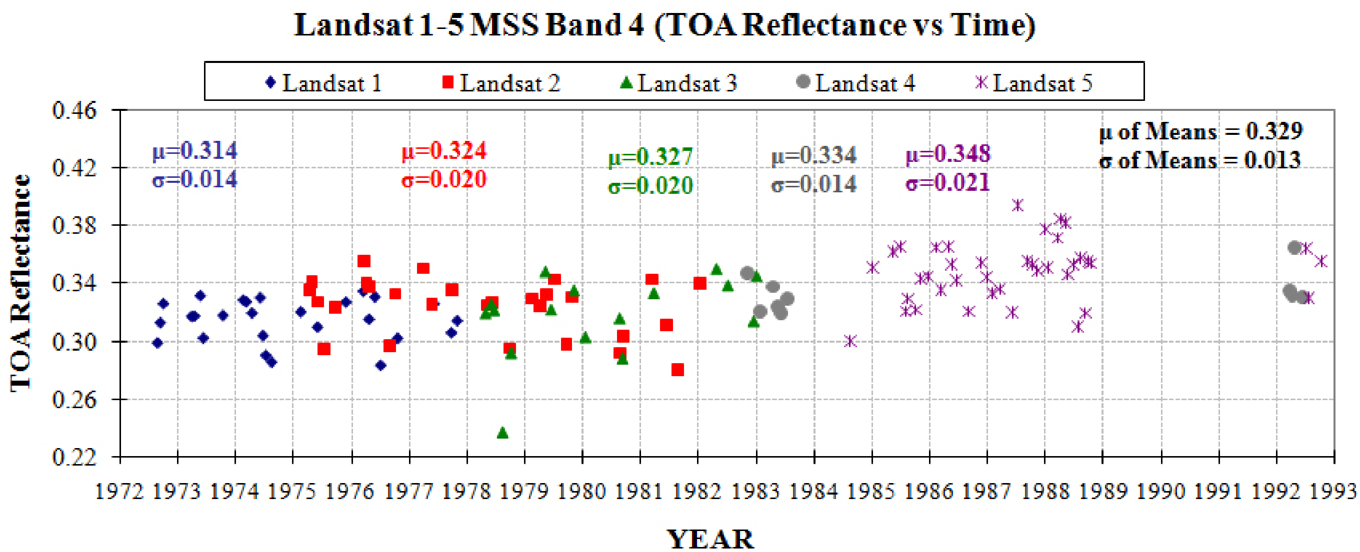
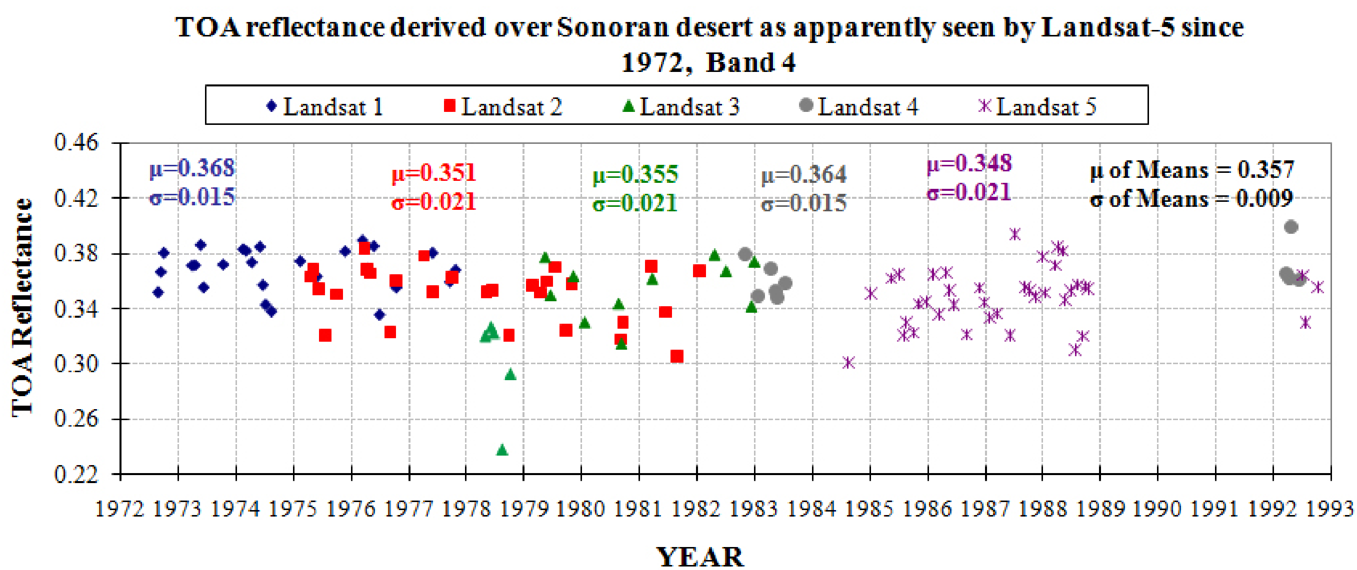
Results: Band 4

Before Cross-calibration applied



After Cross-calibration applied



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Equivalent Landsat-5 MSS TOA Reflectance Conversion Factors for Landsat-1 through -4 MSS

Equivalent Landsat-5 TOA Reflectance Conversion Factors								
Band	Landsat-1			Band	Landsat-2			
	Gain	Offset Term	Time Dependent Term		Gain	Offset Term	Time Dependent Term	
1	0.9343	0.0059	0	1	1.0772	-0.0079	0.0009858*(1982.86-t)	
2	0.8714	0.0183	0	2	1.0334	-0.019	0.0010453*(1982.86-t)	
3	0.9386	0.0114	0	3	1.0081	-0.0149	0	
4	1.0374	0.0422	0	4	1.0426	0.0131	0	
Band	Landsat-3 (Applicable to post-1979 data only)			Band	Landsat-4			
	Gain	Offset Term	Time Dependent Term		Gain	Offset Term	Time Dependent Term	
1	1.0623	-0.0019	0.002611*(1983.05-t)	1	1.1284	0.0014	0	
2	0.9875	-0.0032	0	2	1.079	-0.0035	0	
3	1.0461	0.0039	0	3	1.0466	0.0016	0	
4	1.0794	0.0022	0	4	1.1006	-0.0031	0	

Example: Suppose a TOA reflectance calculation in band 1 over any specified ROI of Landsat-2 scene, LM2041038197611 8AAA04, is found to be 0.234. The Equivalent Landsat-5 TOA is given by,

$$\rho_{L5} = \text{Gain}*\rho_{L2} + \text{Offset} + \text{Time dependent term}$$
$$= 1.0772*0.234 - 0.0079 + 0.0009858*(1982.86-1976.32)$$
$$= 0.251$$

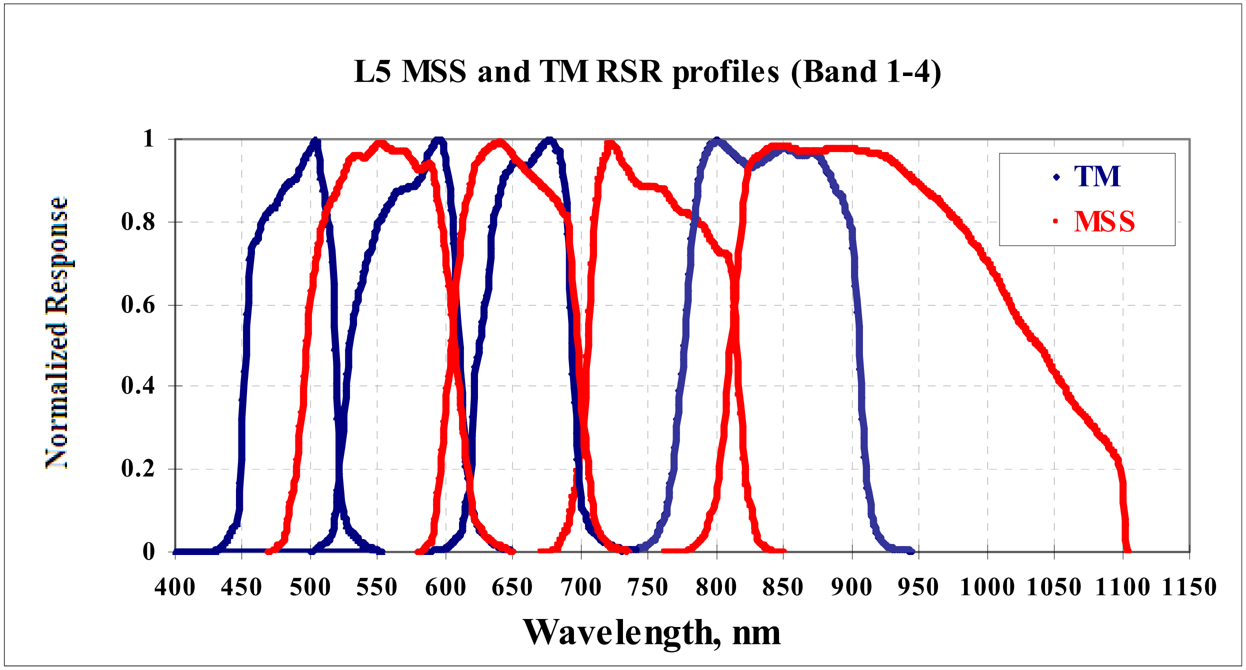
Cross-calibration of Landsat-5 MSS to TM

South Dakota State University
Image Processing Lab

Background

- Landsat-5 TM is known to have an absolute radiometric accuracy of 5%.
- Absolute calibration of MSS sensors can be achieved by establishing a cross-calibration between Landsat-5 MSS and TM.
- Major issues:
  - Spatial resolution
  - RSR Differences

Key Concern: Dissimilar RSR Profiles

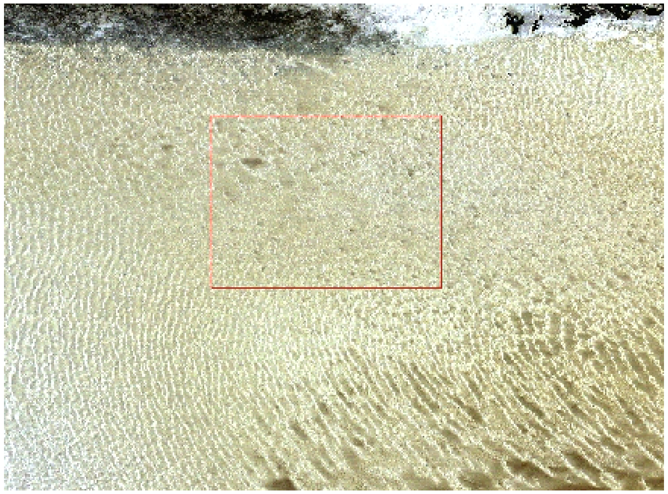


Spectrally best matching pairs

MSS	TM	FOM
B1	B2	0.635
B2	B3	0.708
B3	B4	0.182
B4	B4	0.328

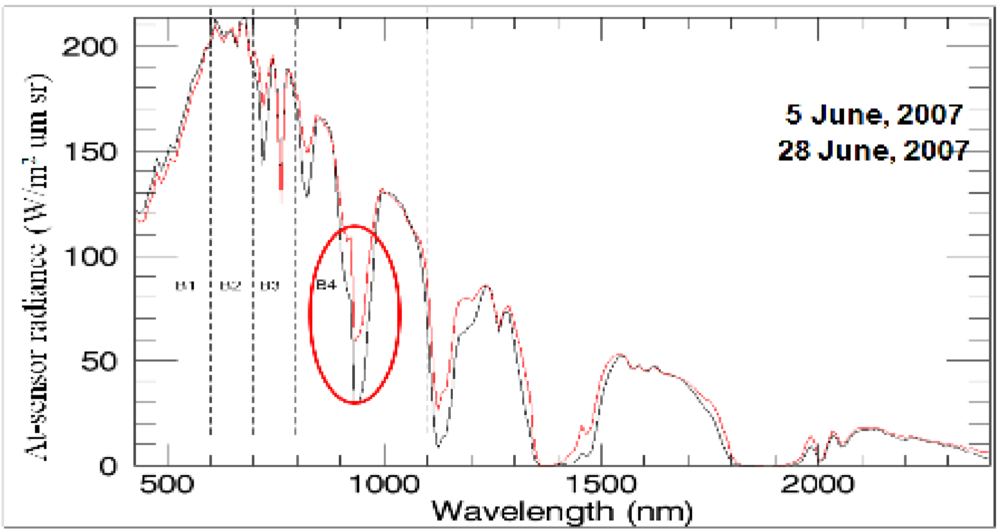
- None of the four bands match closely in their RSR profiles, indicating that the two sensors may produce different results while looking at the same ground target.
- Effect of Spectral Band Difference is scene specific, and we need to know the spectral signature of target as well to find the Spectral Band Adjustment Factors (SBAFs).

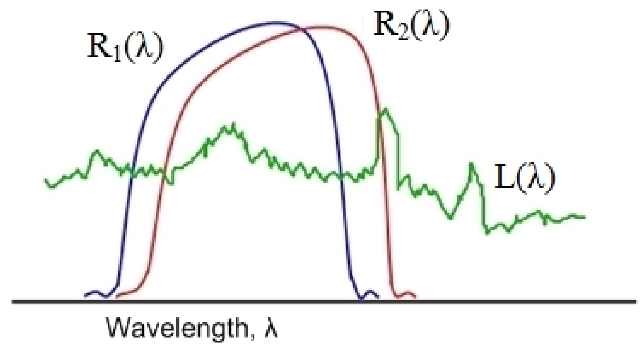
Region of Interest (ROI)



- Twelve pairs of coincident TM and MSS scenes acquired by Landsat-5 over Libya-4 desert PICS site were selected to cross-calibrate MSS to TM.
- 1000×800 pixels ROI defined on MSS scenes (which is equivalent to 1900×2187 TM pixels).
- The dune features in the site were used to geolocate the ROI.

Spectral Band Adjustment Factor (SBAF) Calculation

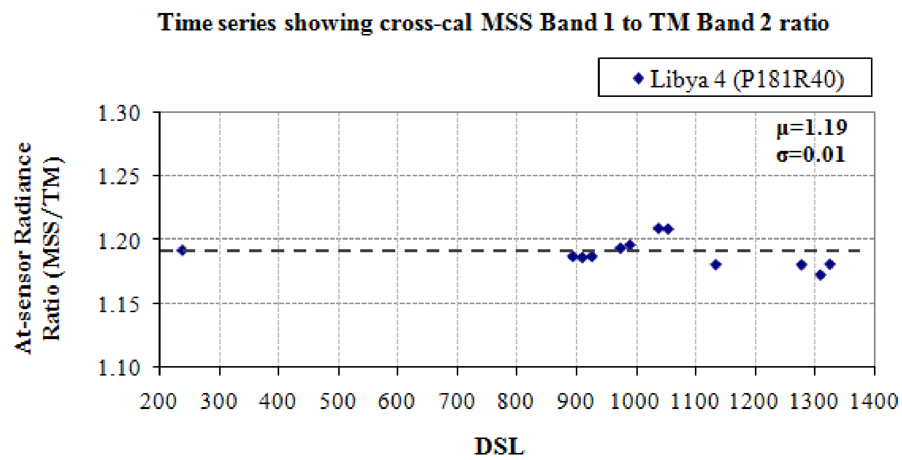


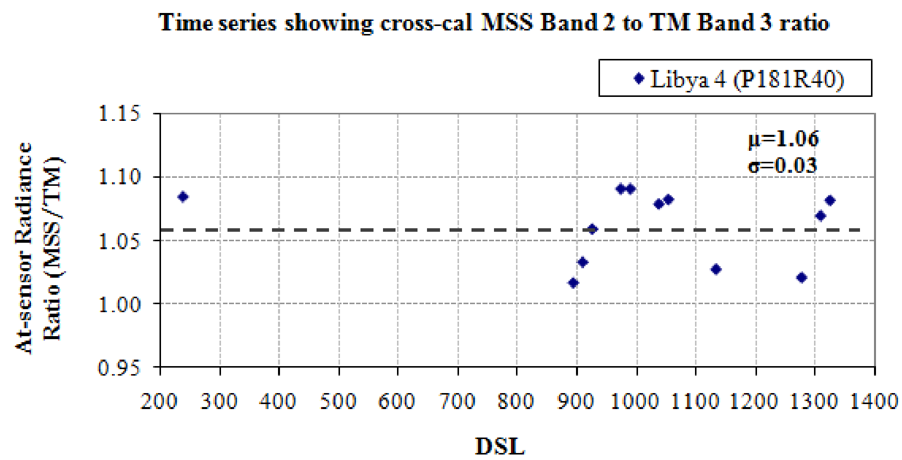


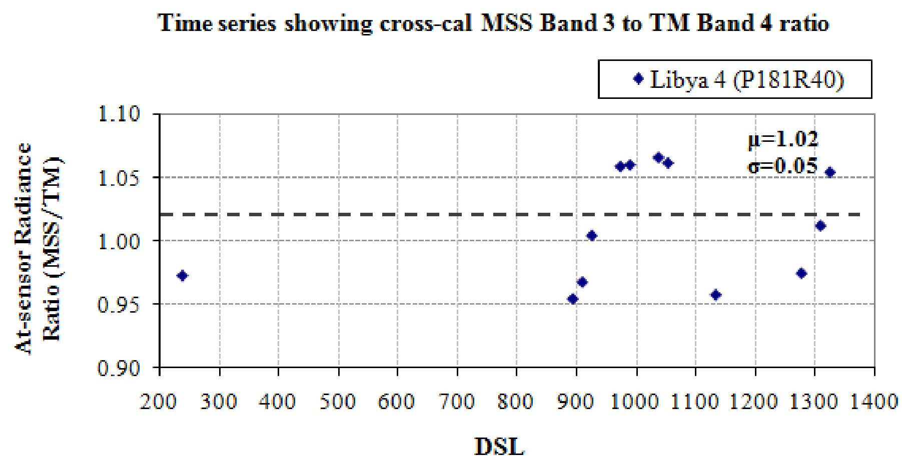
$$SBAF = \frac{\int R_1(\lambda).L(\lambda)d\lambda / \int R_1(\lambda)d\lambda}{\int R_2(\lambda).L(\lambda)d\lambda / \int R_2(\lambda)d\lambda}$$

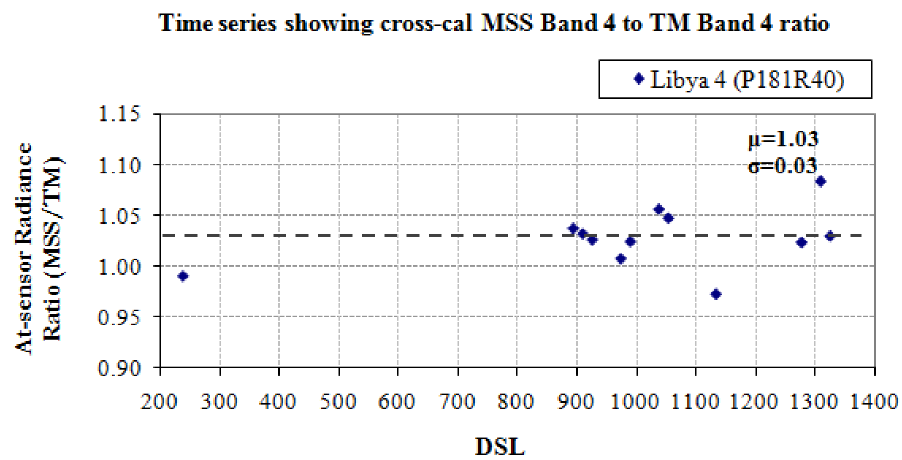
- Spectral signature of Libya-4 desert was derived using hyperspectral data acquired by Hyperion sensor on Earth Observer-1.

Results


Time series showing cross-cal MSS Band 1 to TM Band 2 ratio
Libya 4 (P181R40)
μ=1.19
σ=0.01
At-sensor Radiance Ratio (MSS/TM)
1.30
1.25
1.20
1.15
1.10
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
DSL


Time series showing cross-cal MSS Band 2 to TM Band 3 ratio
Libya 4 (P181R40)
μ=1.06
σ=0.03
At-sensor Radiance Ratio (MSS/TM)
1.15
1.10
1.05
1.00
0.95
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
DSL


Time series showing cross-cal MSS Band 3 to TM Band 4 ratio
Libya 4 (P181R40)
μ=1.02
σ=0.05
At-sensor Radiance Ratio (MSS/TM)
1.10
1.05
1.00
0.95
0.90
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
DSL

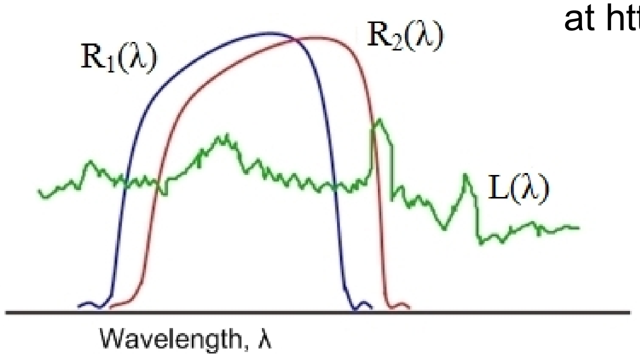

Time series showing cross-cal MSS Band 4 to TM Band 4 ratio
Libya 4 (P181R40)
μ=1.03
σ=0.03
At-sensor Radiance Ratio (MSS/TM)
1.15
1.10
1.05
1.00
0.95
0.90
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
DSL

SBAF Examples

(or how do we perform spectrally dependent cross-cal?)

	Landsat-5 MSS Band	Band 1	Band 2	Band 3	Band 4
	Landsat-5 TM Band	Band 2	Band 3	Band 4	Band 4
Vegetation	Conifer	1.016	0.925	1.221	1.010
	Deciduous	1.019	0.939	1.231	0.996
	Dry Grass	1.062	1.028	1.096	0.927
	Green Grass	1.082	0.919	1.261	0.979
	Cheat Grass	1.076	1.054	1.277	0.872
	Maple Leaf	1.066	0.929	1.268	1.011
	Average:	1.053	0.966	1.226	0.966
	Maximum:	1.016	0.919	1.096	0.872
	Minimum:	1.082	1.054	1.277	1.011
	Range:	0.066	0.134	0.182	0.139

* Spectral profiles obtained from the ASTER Spectral Library available at http://speclib.jpl.nasa.gov



$$SBAF = \frac{\int R_1(\lambda).L(\lambda)d\lambda / \int R_1(\lambda)d\lambda}{\int R_2(\lambda).L(\lambda)d\lambda / \int R_2(\lambda)d\lambda}$$

Conclusions

- The radiometric calibration of each MSS sensor was stable within 2% in band 1, 3% in bands 2 and 3, and 6% in band 4, throughout the lifetime.
  - The absolute gains of five MSS sensors exhibit a maximum difference of 17% as derived from the currently existing radiometrically processed MSS data in the USGS archive.
  - Cross-calibration established (so far) places Landsat-1 through -5 MSS sensors on a consistent radiometric scale to within 6%.
- Initial cross-calibration to Landsat-5 TM using a desert site suggests the absolute radiometric gain of the Landsat-5 MSS is lower in band 1 by 19%, band 2 by 6%, band 3 by 2%, and in band 4 by 3%.
  - Cross-cal of MSS and TM has strong spectral dependencies!
- **Consistent calibration of the Landsat archive is possible back to 1972!**